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User's Manual for the Plume Visibility Model (PLUVUE II)

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USER'S MANUAL FOR THE PLUME VISIBILITY MODEL (PLUVUE II)

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SECTION 1

INTRODUCTION

With the passage of the Clean Air Act Amendments of 1977, Congress declared as a national goal the protection and restoration of visibility in national parks and wilderness areas that have been designated as class I areas. The implementation of a regulatory program designed to achieve this goal requires both the capability of predicting the visual impact of emissions from new or existing sources, and the capability of measuring existing impacts and monitoring progress.

The purpose of this manual is to provide documentation for a plume visibility model, PLUVUE II, which was designed to predict the impacts of a single emission source on visibility in class I areas. This model is a refinement of the plume visibility model PLUVUE developed by Systems Applications, Inc. for the U.S. Environmental Protection Agency (EPA) in 1980. An overview of the 1980 model is described in this volume; however, the reader should refer to earlier reports (Latimer et al., 1978; Johnson et al., 1980) for additional model details and to the EPA report to Congress on visibility (EPA, 1979).

In addition, both this user's manual and the PLUVUE II visibility model should be used in conjunction with other technical guidance documents in this series. In particular, the document entitled "Workbook for Estimating Visibility Impairment" (EPA-450/4-80-031) should be consulted before the plume visibility model is applied.

This chapter presents a brief overview of the model and a discussion of the model limitations that includes the results of model evaluation with the VISTTA data base. Chapter 2 presents a technical overview of the model. Chapter 3 describes the input data needed to exercise PLUVUE II, and Chapter 4 summarizes the outputs obtained with PLUVUE II. A procedure flow chart of the model is presented in Chapter 5. Input and output computer listings of sample PLUVUE II simulations are presented in Appendixes A (observer-based simulation) and B (plume-based simulation). The source code of PLUVUE II is presented in Appendix C. The formulation of the submodel that calculates the diffuse sky radiance is presented in Appendix D.

OVERVIEW OF THE MODEL

The design objective of the PLUVUE II model is to calculate visual range reduction and atmospheric discoloration caused by plumes consisting of primary particles, nitrogen oxides, and sulfur oxides emitted by a single emission source. Primary emissions of sulfur dioxide (SO_2) and nitric oxide (NO) do not scatter or absorb light and therefore do not cause visibility impairment. However, these emissions are converted in the atmosphere to secondary species that do scatter or absorb light and thus have the potential to cause visibility impairment. SO_2 emissions are converted to sulfate ($SO_4^{=}$) aerosols. These aerosols are generally formed or grow to a size (0.1 to 1.0 μm) that is effective in scattering light. Nitric oxide (NO) emissions are converted to nitrogen dioxide (NO_2) gas, which is effective in absorbing light. In turn, NO_2 is converted to nitric acid vapor (HNO_3), which neither absorbs nor scatters light. In some situations, nitric acid may form ammonium nitrate or organic nitrate aerosol, which scatters light. However, in many nonurban plumes nitrate probably remains as HNO_3 vapor without visual effects. Eventually, all primary particles, secondary aerosols, and gases in a plume are removed from the atmosphere as a result of surface deposition and precipitation scavenging. PLUVUE II is designed to predict the transport, atmospheric diffusion, chemical conversion, optical effects, and surface deposition of point-source emissions.

The PLUVUE II model uses a Gaussian formulation for transport and dispersion. The spectral radiance $I(\lambda)$ (i.e., the intensity of light) at 39 visible wavelengths ($0.36 < \lambda < 0.75$ μm) is calculated for views with and without the plume; the changes in the spectrum are used to calculate various parameters that predict the perceptibility of the plume and contrast reduction caused by the plume (see Latimer et al., 1978). The four key perception parameters for predicting visual impact are

> Reduction in visual range.

> Contrast of the plume against a viewing background at the 0.55 μm wavelength.

> The blue-red ratio of the plume.

> The color change perception parameter $\Delta E(L^*a^*b^*)$.

PLUVUE II is designed to perform plume optics calculations in two modes. In the plume-based mode, the visual effects are calculated for a variety of lines of sight and observer locations relative to the plume parcel; in the observer-based mode, the observer position is fixed and visual effects are calculated for the specific geometry defined by the positions of the observer, plume, and sun. For either mode, the model requires the user to select up to 16 different distances downwind of the emission source. These distances determine the locations of the optics calculations along the plume trajectory.

For the plume-based calculations, the distance downwind of the emission source is the main reference. At each distance, calculations are done for a range of

> Scattering angles (θ).

> Azimuthal angles (α) between the line of sight and the plume centerline.

> Elevation angles (β) of the line of sight.

> Distances from the observer to the plume centerline (r_p) and from the observer to the background viewing object (terrain) behind the plume (r_o).

For the observer-based calculations, both the observer position and the direction of the plume trajectory are fixed by user-supplied specifications appropriate to the given application:

> Wind direction
> Location of the source
> Location of the observer
> Date and time.

These specifications allow the specific plume-observer geometry (θ, α, β, r_p) to be calculated for each downwind distance on the plume trajectory. Calculations are performed for lines of sight emanating from the observer's location and through the plume center at various downwind distances. Each line of sight is matched with its particular set of specifications.

For either plume-based or observer-based calculations, there are four types of calculations that can be performed at each downwind distance. The first calculates the effects for horizontal lines of sight with a clear sky background. Plume-based calculations include a range of scattering angles (θ), azimuthal angles between the line of sight and the plume centerline (α), and observer-to-plume distances (r_p). The observer-based computation uses the specific values of these variables for each downwind point appropriate for the given plume-observer geometry.

The second type of calculation is for nonhorizontal views of the plume with a clear sky background. The plume-based calculations include a range of different elevation angles (β) for the line of sight, in addition to the three parameters that vary in the horizontal view calculations. The observer-based calculations are done only once for the specific angles and distances of each point of analysis along the plume trajectory.

The third type of calculation evaluates the effect of the plume on horizontal views with white, gray, and black viewing object (terrain) backgrounds with uniform spectral reflectances of 1.0, 0.3, and 0.0, respectively. The plume-based calculations are done for the range of scattering angles (Θ), observer-to-plume distances (r_p) and observer-to-background object distances (r_o), assuming that the line of sight is perpendicular to the plume centerline ($\alpha = 90°$). However, in the observer-based calculations, the values of the angles and distances for the specific geometry are used.

The fourth type of calculation is performed for views looking down the centerline of the plume toward the source. The plume-based calculations consider the range of plume segment lengths (Δx) along the plume. These segments are determined by the analysis points (up to 16) used to specify the plume trajectory. The calculations are also done for a range of distances from the observer to the plume (r_p) for each different plume segment. The observer-based calculations are much simpler for this case because all the distances and angles are specified; it is assumed that the azimuthal angle between the observer's line of sight and the plume centerline is small, but not zero. The observer-based calculations are done for white, gray, and black object (terrain) viewing backgrounds, as well as for the sky viewing background.

LIMITATIONS OF THE MODEL

The plume visibility models PLUVUE and PLUVUE II have been evaluated with the VISTTA data base. The original PLUVUE model was evaluated with the 1979 VISTTA data base, which was collected in the vicinity of the Navajo generating station near Page, Arizona. This power plant emits small amounts of particles (Candelaria and Palomino, 1982), and secondary aerosol formation in the plume was observed and calculated to be slow (Richards et al., 1981; Wilson and McMurry, 1981; Seigneur, 1982). Thus, the visual effects of the Navajo power plant plume are primarily due to NO_2 light absorption. The improved version of PLUVUE II was evaluated with the 1981 VISTTA data base that was collected in the vicinity of the Kincaid generating station near Springfield, Illinois, the Labadie generating station near St. Louis, Missouri, and the Magma copper smelter near San Manuel, Arizona. We next present an overview of these model evaluation results. Detailed presentations of the model evaluation results have been given by Seigneur, Hudischewskyj, and Bergstrom (1982) and Bergstrom et al. (1981) for the 1979 VISTTA case studies, and by Seigneur et al. (1983b) for the 1981 VISTTA case studies.

For applications to distant class I areas (more than 50 km from the emission source), the model is undoubtedly less accurate because of mesoscale wind speed, wind direction, and stability variations. Thus, the use of a Gaussian-based model for downwind distances greater than 50 km to predict visual effects is probably a conservative approach (i.e., it overestimates impacts); however, this has not yet been demonstrated conclusively. Visual impacts for horizontal lines of sight are inversely proportional to the vertical extent of plume mixing. This vertical extent of plume mixing is defined by the vertical plume dispersion parameter (σ_z) and, at farther downwind distances, by the mixing depth. Thus, errors in predicting vertical plume dimensions will carry throughout the calculations of plume visibility impacts. However, until field measurements of mesoscale plume transport and diffusion are carried out, and until better models based on these data are developed and verified, we do not know of a better approach to modeling plume dispersion for the purposes of visibility modeling than that provided in PLUVUE II.

PLUVUE II dispersion calculations are based on the standard Pasquill-Gifford σ_y and σ_z values. However, the PLUVUE II user has the option to supply σ_y, σ_z values based on measurements or other σ_y, σ_z parameterizations, if these are more appropriate for a given application.

Other limitations are basic to the chemical mechanism used in PLUVUE II to predict the conversion of sulfur and nitrogen oxides. Although this mechanism is a reasonable approximation for most applications in nonurban areas, it is not valid for applications in photochemical (urban) atmospheres or for sources of significant quantities of reactive hydrocarbons. For such applications, photochemical plume models or regional models should be used.

Other approximations are used in the atmospheric optics calculations and are discussed in Latimer et al. (1978). These approximations probably do not introduce significant errors in most situations; however, this has not yet been demonstrated to be the case. Terrain viewing backgrounds are idealized as white, gray, and black objects. The background atmosphere is treated as two layers: a homogeneous, surface mixed layer and a relatively clean upper-atmosphere layer. Diffuse radiation is now calculated by integrating an angle-dependent radiance field according to the algorithm of Isaacs (1981, Appendix D). Errors in predicting diffuse-radiation intensities may adversely affect the accuracy of spectral radiance calculations, but not necessarily the accuracy of calculations of plume contrast, color differences, and reduction in visual range.

In PLUVUE II, the calculated visual impact of a plume is quantified using coloration, color difference, and contrast parameters that are related to human visual perception. The relationships between these optical parameters and the perceived scenic beauty of national parks and wilderness areas (which is the basic quality that the national visibility goal is designed to protect) have been the subject of several reports (Rowe and Chestnut, 1983; Latimer, Daniel, and Hogo, 1980).

The overall evaluation of PLUVUE with the 1979 VISTTA data base was performed for three different types of background conditions:

> Clear-sky background (20 case studies using data from 13 July, 7 December, and 15 December, 1979).

> Dark-mountain background (2 case studies using data from 28 June 1979).

> Hazy-sky background (5 case studies using data from 4 December 1979).

Simulations were carried out on the basis of emission, meteorological, and background air quality data--the inputs listed in the 1979 VISTTA data base (Seigneur et al., 1982).

Evaluation of the dispersion and chemistry modules was conducted from case studies in which the aircraft had flown through the approximate plume centerline. The evaluation of the optics module was conducted for 10 cases from 7 December 1979, for which there was good alignment between the telephotometer sight path and the aircraft flight path. Thus, the aircraft measurements could be used as direct inputs to the optics modules.

Results of the PLUVUE evaluation indicate the following conclusions for the conditions considered:

> PLUVUE tends to overpredict the plume visual effects; the average absolute relative errors in plume contrast are 69, 83, 69, and 154 percent at 405, 450, 550, and 630 nm, respectively. The larger error at 630 nm is due to the fact that observed plume contrasts are small in the red light range and are therefore difficult to predict accurately.

> The PLUVUE dispersion module appears to contain the primary source of uncertainty in model predictions: plume dispersion is generally underestimated by the modules.

> Predictions of the PLUVUE chemistry module show reasonable agreement with measurements of the NO_2/NO_x ratio, considering the uncertainties introduced by the dispersion module because of the dependence of plume chemistry on plume dispersion.

> The PLUVUE optics module compares satisfactorily with the case studies. Average absolute relative errors in plume contrast are 47, 45, 39, and 164 percent at 405, 450, 550, and 630 nm, respectively. The evaluation of the PLUVUE optics module shows that the plume visual effects were overestimated in 9 out of the 10 case studies. Correlation coefficients between observations and predictions are 0.70, 0.84, 0.77, and 0.21 at 405, 450, 550, and 630 nm, respectively. Thus, PLUVUE optics module performance is quite satisfactory in the blue and green range for which plume visual effects are important.

PLUVUE II differs from PLUVUE in its improved treatment of the multiple scattering of light by aerosols and light absorption by carbonaceous aerosols. Light absorption by NO_2 is treated in the same manner in PLUVUE II as it is in PLUVUE. Therefore, the evaluation of PLUVUE II with the 1979 VISTTA case studies that are characterized mainly by NO_2-laden plumes was not repeated. The 1981 VISTTA data base (Seigneur et al., 1983a) presents nine case studies of particle plumes. These data were collected at the Kincaid power plant in Illinois, the Labadie power plant in Missouri, and the San Manuel smelter in Arizona. The 1981 VISTTA data base was used to evaluate PLUVUE II under conditions in which scattering of light particles is important.

Model simulations were conducted to evaluate the overall plume visibility model PLUVUE II as well as the optics module. The following conclusions can be drawn from the evaluation of PLUVUE II:

> PLUVUE II tends to overpredict plume visual effects; the average absolute relative errors in plume contrast are 134, 134, 153, and 79 percent at 405, 450, 550, and 630 nm, respectively. These results show that it is more difficult to predict the visual effects of particulate plumes than those of NO_2-laden plumes, since better model performance was obtained for the NO_2-laden plumes of the 1979 VISTTA data base.

> The dispersion module overestimates plume dispersion by a factor of 1.5 to 2.

> The PLUVUE II optics module tends to overpredict plume visual effects; the average absolute relative errors in plume contrast are 140, 78, 72, and 111 percent at 405, 450, 550, and 630 nm, respectively. The optics module appears to underpredict forward scattering of light by aerosols, i.e., it predicts a darker plume than is observed for scattering angles less than 90 degrees.

SECTION 2

TECHNICAL OVERVIEW

This chapter briefly outlines the technical details of the plume visibility model (PLUVUE II). Those interested in more detail should consult Latimer et al. (1978).

As shown schematically in figure 1, the modeling of visibility impairment requires mathematical descriptions for the following physical and chemical atmospheric processes in succession:

- Emissions.
- Atmospheric transport, diffusion, and removal.
- Chemical and physical reactions and transformations of precursors in the atmosphere.
- Light scattering and absorption characteristics of the resultant aerosol.
- Radiative transfer through the aerosol along different lines of sight.

Because the visibility model is based on atmospheric dispersion and chemistry models, the accuracy of the former depends on that of the latter. We recognize that future improvements in modeling dispersion--particularly on the regional scale and in complex terrain, as well as improvements in modeling secondary aerosol formation--will increase the accuracy of visibility models.

POLLUTANT TRANSPORT, DIFFUSION, AND REMOVAL

There are two scales that are of interest in visibility impairment calculations. They require two different types of models:

- A near-source plume model designed to predict the incremental impact of one emissions source (such as a power plant or smelter).

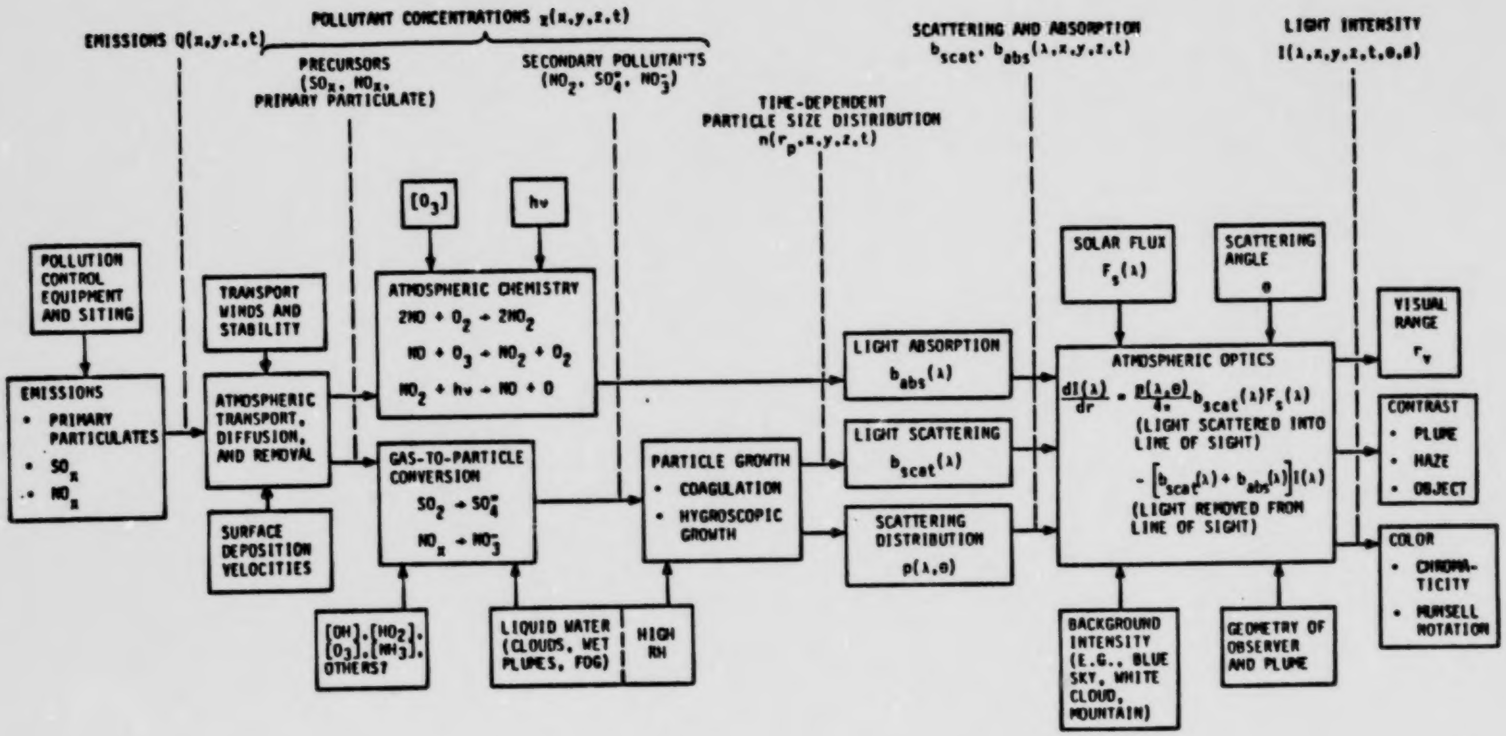

EMISSIONS $Q(x,y,z,t)$
POLLUTANT CONCENTRATIONS $\chi(x,y,z,t)$
PRECURSORS (SO_x, NO_x, PRIMARY PARTICULATE)
SECONDARY POLLUTANTS (NO_2, $SO_4^=$, NO_3^-)
TIME-DEPENDENT PARTICLE SIZE DISTRIBUTION $n(r_p,x,y,z,t)$
SCATTERING AND ABSORPTION b_{scat}, $b_{abs}(\lambda,x,y,z,t)$
LIGHT INTENSITY $I(\lambda,x,y,z,t,\theta,\phi)$
POLLUTION CONTROL EQUIPMENT AND SITING
EMISSIONS
• PRIMARY PARTICULATES
• SO_x
• NO_x
TRANSPORT WINDS AND STABILITY
ATMOSPHERIC TRANSPORT, DIFFUSION, AND REMOVAL
SURFACE DEPOSITION VELOCITIES
$[O_3]$
$h\nu$
ATMOSPHERIC CHEMISTRY
$2NO + O_2 \rightarrow 2NO_2$
$NO + O_3 \rightarrow NO_2 + O_2$
$NO_2 + h\nu \rightarrow NO + O$
GAS-TO-PARTICLE CONVERSION
$SO_2 \rightarrow SO_4^=$
$NO_x \rightarrow NO_3^-$
$[OH]$, $[HO_2]$, $[O_3]$, $[NH_3]$, OTHERS?
LIQUID WATER (CLOUDS, WET PLUMES, FOG)
HIGH RH
PARTICLE GROWTH
• COAGULATION
• HYGROSCOPIC GROWTH
LIGHT ABSORPTION $b_{abs}(\lambda)$
LIGHT SCATTERING $b_{scat}(\lambda)$
SCATTERING DISTRIBUTION $p(\lambda,\theta)$
SOLAR FLUX $F_s(\lambda)$
SCATTERING ANGLE θ
ATMOSPHERIC OPTICS
$\frac{dI(\lambda)}{dr} = \frac{p(\lambda,\theta)}{4\pi} b_{scat}(\lambda) F_s(\lambda)$
(LIGHT SCATTERED INTO LINE OF SIGHT)
$- \left[b_{scat}(\lambda) + b_{abs}(\lambda)\right] I(\lambda)$
(LIGHT REMOVED FROM LINE OF SIGHT)
BACKGROUND INTENSITY (E.G., BLUE SKY, WHITE CLOUD, MOUNTAIN)
GEOMETRY OF OBSERVER AND PLUME
VISUAL RANGE r_v
CONTRAST
• PLUME
• HAZE
• OBJECT
COLOR
• CHROMATICITY
• MUNSELL NOTATION

Figure 1. Schematic logic flow diagram of the plume visibility model.

- A regional model designed to predict, over time periods of several days, the impacts of several emissions sources within a region whose spatial scale is in the range of 1000 km.

Calculation of near-source visual impacts, which is the design objective of PLUVUE, requires a basic model that accurately predicts the spatial distribution of pollutants and the chemical conversion of NO to NO_2 and SO_x and NO_x to sulfates and nitrates. The plume model must be capable of handling the spatial scale from emissions at the source to at least 100 km downwind. Because the regional-scale problem may be caused by the long-range transport of pollutants over a spatial scale of 1000 km, an air quality model is needed that can account for multiple sources and for temporal variations in mixing heights, dispersion parameters, emission rates, reaction rates, and wind speed and direction. This second type of model, a regional visibility model, is beyond the scope of this user's manual. PLUVUE is a near-source plume visibility model.

In the following subsections, we discuss atmospheric dispersion modeling as it relates to the plume visibility model for the following spatial scales:

- Initial dilution in a buoyant plume
- Gaussian plume diffusion
- Limitations on mixing.

Initial Dilution in a Buoyant Plume

Modeling of the initial dilution of a plume from the top of the stack to the point of final plume rise is important when modeling the conversion of nitric oxide to nitrogen dioxide in a power plant plume because of the quick quenching of the thermal oxidation of NO. The rate of this reaction is second order with respect to NO concentrations; therefore, the rate is fastest in the initial stages of plume dilution. It is also important to account for the initial dilution of buoyant releases because the rate of dilution caused by the turbulent entrainment of ambient air by a rising plume parcel can be considerably greater than that indicated by diffusion coefficients based on measurements for nonbuoyant releases (e.g., Pasquill-Gifford σ_y, σ_z). Thus, initial plume dilution during plume rise should be taken into account to calculate accurately both plume dilution and atmospheric chemistry.

Briggs (1969) suggested that the characteristic plume radius increases linearly with the height of the plume above the stack and can be represented as follows:

$$R_p = 0.5\ (\Delta h) \quad . \tag{1}$$

Briggs described plume rise, as a function of downwind distance (the "2/3 power law"), as follows:

$$\Delta h = 1.6\ F^{1/3} x^{2/3} u^{-1} \quad . \tag{2}$$

For initial dilution, we can assume that the plume is circular in cross section and has a Gaussian profile. We can also assume that the radius of the plume is the distance from the plume centerline to the point at which the plume concentration is 10 percent of the centerline concentration. Thus, we have

$$R_p = y_p = z_p = 2.15\ \sigma_y = 2.15\ \sigma_z \quad . \tag{3}$$

The concentration of a given species at the centerline of the plume can be calculated by a modified Gaussian model that can be represented as

$$\chi = \frac{Q}{2\pi\sigma_y\sigma_z V} \tag{4}$$

where V is the velocity of the parcel, which has a horizontal component (the wind speed u) and a vertical component w, which can be calculated by differentiating equation (2). Thus

$$w = \frac{dz}{dt} = \frac{2}{3}\ 1.6\ F^{1/3} u^{-1/3} t^{-1/3} \quad . \tag{5}$$

With this formulation, time-dependent plume temperature and NO concentrations can be calculated for accurately predicting the thermal oxidation of NO during plume rise.

Combining equations (1), (3), and (4), we can calculate the initial dilution of plume material, after the plume has reached its final height, as follows:

$$\chi = \frac{2.94\ Q}{(\Delta h)^2 u} \tag{6}$$

Thus, plume material is assumed to be at least as dilute as that shown by equation (6). For emissions sources having more than one stack, it is assumed that there is an overlap of plumes from individual stacks. For cases in which the initial dilution during plume rise is greater than the standard Gaussian formula would predict at the downwind distance of final plume rise, a virtual point-source offset is introduced so that dilution at this distance is at least as much as that shown in equation (6).

Plume Rise

The final plume rise in PLUVUE is calculated using the modified plume rise formulas of Briggs (1969, 1971, 1972):

For unstable or neutral atmospheric conditions, the downwind distance of final plume rise is $x_f = 3.5\ x^*$, where

$$x^* = \begin{cases} 14\ F^{5/8}, \text{ if } F < 55\ m^4 s^{-3} \\ 34\ F^{2/5}, \text{ if } F \geq 55\ m^4 s^{-3} \end{cases} \quad . \tag{7}$$

The final plume rise under these conditions is

$$\Delta h = 1.6\ F^{1/3} (3.5\ x^*)^{2/3} u^{-1} \quad . \tag{8}$$

For stable atmospheric conditions, the downwind distance of final plume rise is $x_f = \pi\ u\ s^{-1/2}$, where the stability parameter s is defined as follows:

$$s = g\ \partial\theta/\partial z\ T^{-1} \quad . \tag{9}$$

The plume rise for stable atmospheric conditions is

$$\Delta h = \text{minimum of} \begin{cases} 2.6(F/(u\ s))^{1/3} \\ 5\ F^{1/4} s^{-3/8} \end{cases} \quad . \tag{10}$$

The buoyancy flux (F) in the above equations is calculated on the basis of the flue gas volumetric flow rate per stack ($\dot{V}$), flue gas and ambient temperature in degrees Kelvin (T_{stack}, $T_{ambient}$), and gravitational acceleration (g), as follows:

$$F = \frac{g\dot{V}}{\pi} \left(1 - \frac{T_{ambient}}{T_{stack}}\right) \quad . \tag{11}$$

Gaussian Plume Diffusion

After the plume has achieved its final height (about 1 km downwind), plume concentrations for uniform wind fields can be adequately predicted using a Gaussian model if the wind speed u at plume height H ($h_s + \Delta h$) and the rate of diffusion are known for the particular situation so that diffusion coefficients (σ_y, σ_z) can be selected:

$$\chi = \frac{Q}{2\pi\sigma_y\sigma_z u} \exp\left[-\frac{1}{2}\left(\frac{y}{\sigma_y}\right)^2\right] \left\{\exp\left[-\frac{1}{2}\left(\frac{H+z}{\sigma_z}\right)^2\right] + \exp\left[-\frac{1}{2}\left(\frac{H-z}{\sigma_z}\right)^2\right]\right\} . \tag{12}$$

Equation (12) is appropriate for a conservative species and can be modified to be appropriate for a nonconservative species by changing the source term Q.

It is necessary for calculating plume visual impact to integrate, along the line of sight, the plume extinction coefficient, the magnitude of which depends on primary and secondary particulate and nitrogen dioxide concentrations. Equation (12) can be integrated [Ensor, Sparks, and Pilat (1973)] in the cross-wind direction y, from $y = -\infty$ to $y = +\infty$, to obtain the optical thickness of the plume:

$$\tau_{py} = \int_{-\infty}^{+\infty} b_{ext}\, dy = \frac{Q'(x)}{(2\pi)^{1/2}\sigma_z u} \left\{\exp\left[-\frac{1}{2}\left(\frac{H+z}{\sigma_z}\right)^2\right] + \exp\left[-\frac{1}{2}\left(\frac{H-z}{\sigma_z}\right)^2\right]\right\} , \tag{13}$$

where b_{ext} is the incremental increase in extinction coefficient in the plume and Q' is the flux of the plume extinction coefficient over the entire plume cross section at downwind distance x. In the vertical direction z, from $z = 0$ to $z = +\infty$, the plume optical thickness is

$$\tau_{pz} = \int_0^\infty b_{ext}\, dz = \frac{Q'(x)}{(2\pi)^{1/2}\, \sigma_y u} \exp\left[-\frac{1}{2}\left(\frac{y}{\sigma_y}\right)^2\right] \quad . \qquad (14)$$

Observer-Plume Orientation

The magnitude of the visual impact of a plume depends on the orientation of the observer with respect to the plume because the plume optical thickness will vary depending on this orientation. Figure 2 shows plan and elevation views of an observer and a plume and indicates that the sight path distance through the constituents of the plume is a function of angles α and β. The optical thickness for most combinations of angles α and β can be approximated as follows:

$$\tau_p(\alpha,\beta) = \frac{1}{\sin\alpha}\left[\left(\tau_{py}\cos\beta\right)^2 + \left(\tau_{pz}\sin\beta\right)^2\right]^{1/2} \quad . \qquad (15)$$

Figure 2 suggests that plume optical thickness is greater for horizontal sight paths than vertical ones, particularly during stable conditions when the plume cross section is flattened.

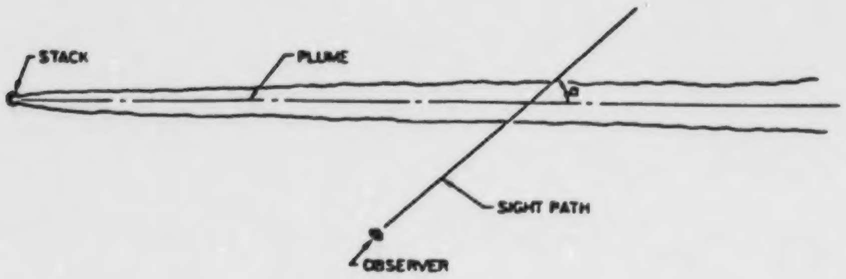
Limited Mixing

When vertical diffusion is limited by a stable capping layer, equation (12) is no longer valid, and a Gaussian formulation, with terms for reflection from the top of the mixed layer (at altitude H_m), is used. Let H' be the height of the virtual source positioned above the top of the mixed layer:

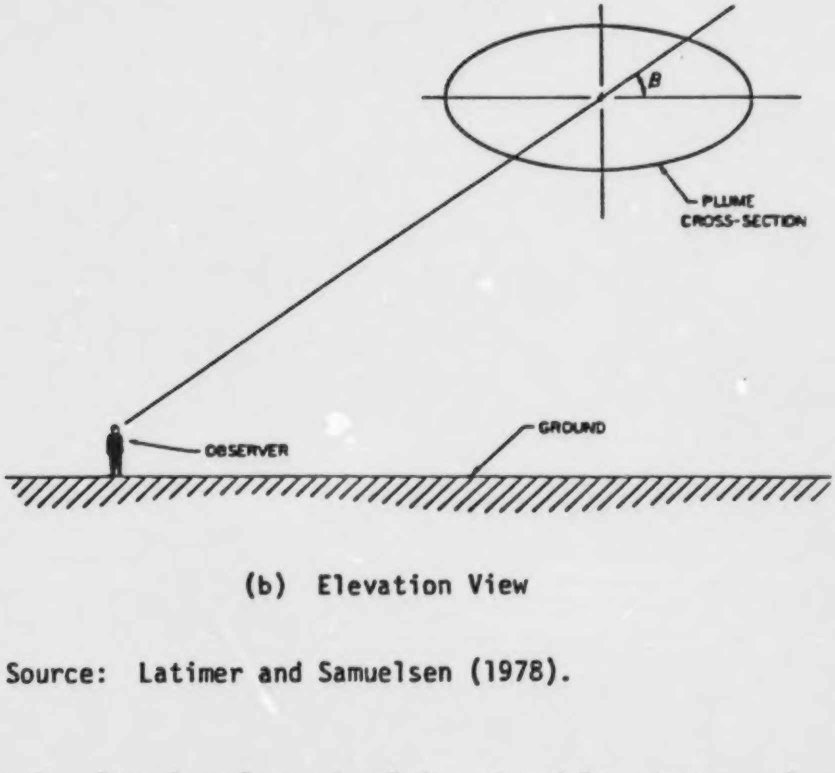
$$H' = 2\, H_m - H \quad .$$

The Gaussian formulation for limited mixing is

$$\chi = \frac{Q}{2\pi\, \sigma_y \sigma_z\, u} \exp\left[-\frac{1}{2}\left(\frac{y}{\sigma_y}\right)^2\right]\left\{\exp\left[-\frac{1}{2}\left(\frac{H+z}{\sigma_z}\right)^2\right] + \exp -\left[\frac{1}{2}\left(\frac{H-z}{\sigma_z}\right)^2\right]\right.$$
$$\left. + \exp\left[-\frac{1}{2}\left(\frac{H'-z}{\sigma_z}\right)^2\right] + \left[\exp -\frac{1}{2}\left(\frac{H'+z}{\sigma_z}\right)^2\right]\right\} \quad . \qquad (16)$$


STACK
PLUME
β
SIGHT PATH
OBSERVER

(a) Plan View


β
PLUME
CROSS-SECTION
OBSERVER
GROUND

(b) Elevation View

Source: Latimer and Samuelsen (1978).

Figure 2. Gaussian plume visual impact model: observer-plume geometry.

In this instance of limited mixing, the plume material eventually becomes uniformly mixed in the vertical direction for $0 < z < H_m$. In the limit, the concentration is expressed as follows:

$$\chi = \frac{Q}{(2\pi)^{1/2} \sigma_y u H_m} \exp \left[- \frac{1}{2} \left(\frac{y}{\sigma_y} \right)^2 \right] \quad . \tag{17}$$

The calculation of plume optical thickness in the y-direction becomes simply

$$\tau_{py} = \frac{Q'(x)}{uH_m} \quad . \tag{18}$$

Surface Deposition

Surface deposition is calculated by integrating the plume concentrations at the ground and multiplying by a deposition velocity, V_d, that characterizes gas and particulate surface depletion:

$$- \frac{dQ}{dx} = V_d \int \chi \, dy \tag{19}$$

Since nocturnal ground-based stable layers shield a plume from the ground at night, surface deposition is effectively zero at night. This is handled in the model using a flag keyed to the time of day at which the plume parcel is at a given downwind distance.

Power Law Wind Profile Extrapolation of Surface Winds

PLUVUE II is designed to use either wind speed aloft or surface wind speed (commonly measured at 7 m above the surface). The power law extrapolation presented in "User's Manual for a Single-Source (CRSTER) Model" (EPA, 1977) is used. The surface wind speed is extrapolated to stack height for the plume rise calculation, and the surface wind speed is extrapolated to the final plume height for Gaussian concentration calculations. The power law extrapolation is as follows:

$$u = u_0 \, (z/7)^P \tag{20}$$

where

u = wind speed at altitude z (ms^{-1})
u_0 = surface wind speed (ms^{-1})

The profile exponent p is a function of stability and has the following values:

Pasquill Stability Class		Wind Speed Profile Exponent (p)
A	Extremely unstable	0.10
B	Moderately unstable	0.15
C	Slightly unstable	0.20
D	Neutral	0.25
E	Slightly stable	0.30
F	Moderately stable	0.30

ATMOSPHERIC CHEMISTRY

As shown in figure 1, the conversion of emissions of nitric oxide (NO) and sulfur dioxide (SO_2) to nitrogen dioxide (NO_2) gas and sulfate ($SO_4^=$) aerosol--species responsible for visual effects--must be calculated in the visibility model.

The rate of chemical conversion of these primary emissions to secondary species responsible for visual impact is dependent on the concentration of the reacting species and ultraviolet (UV) solar flux. Thus, conversion rates are dependent on both plume dilution and time of day. A plume parcel at a given downwind distance has a specific age, time of emission, and history of UV irradiation, which can affect the amount of NO_2 and $SO_4^=$ in the plume at a given time. Thus, the chemical conversion in each plume parcel must be treated separately, taking into account these factors.

PLUVUE II is structured to take a "snapshot" of a plume at a given time. In PLUVUE II, the chemical conversion is calculated for each plume parcel, observed at a given distance, in a Lagrangian manner; i.e., the reaction rates are calculated at each of several discrete downwind distances and times from the point of emission to the downwind distance at which the plume parcel is observed. Thus, the age of a plume parcel observed at downwind distance x_{obs} is x_{obs}/u, where u is the wind speed. The time at which a plume parcel is at a given downwind distance relates to the time of observation as follows:

$$t = t_{obs} - \frac{x_{obs} - x}{u} \qquad (21)$$

The UV flux is calculated as a function of time that a plume parcel is at a given downwind distance x from the solar zenith angle (i.e., the angle between direct solar rays and the normal to the earth's surface). The zenith angle is calculated on the basis of the latitude, longitude, date, and time using a subroutine developed by Schere and Demerjian (1977).

The rate of chemical conversion is also dependent on the location of the plume parcel within the plume. PLUVUE II makes calculations at the following altitudes within the plume ($y = 0$): at the plume centerline ($z = H$) and at $z = H \pm n\,\sigma_z$, where $n = 1$ and 2.

Conversion of NO to NO_2

Nitrogen dioxide gas can cause a yellow-brown discoloration of the atmosphere. Although some discoloration is a result of wavelength-dependent light scattering caused by submicron aerosol, as discussed in the workbook of this regulatory guidance series, the dominant colorant of power plant plumes is NO_2, which causes a yellow-brown discoloration that may be apparent at significant distances downwind of large coal-fired power plants, particularly in areas where the background visual range is excellent.

Very little NO_2 is emitted directly from combustion sources. However, colorless nitric oxide is formed by the thermal oxidation of atmospheric nitrogen at the high temperatures experienced in the combustion zone (the boiler in a power plant) and the oxidation of nitrogen that may be present in the fuel. Chemical reactions in the atmosphere can form sufficient NO_2 from NO to cause atmospheric discoloration. Available measurements of NO and NO_2 concentrations in power plant plumes in non-urban areas suggest that the conversion of NO to NO_2 can be calculated from a simple set of three reactions.*

The first of these is the thermal oxidation of NO to NO_2:

$$2NO + O_2 \rightarrow 2NO_2 \quad . \tag{22}$$

The reaction is termolecular, but bimolecular with respect to NO; it is therefore very fast at high concentrations of NO but slow at the lower concentrations that exist in the atmosphere or in a plume. The reaction rate for equation (22), based on Baulch, Drysdale, and Horne (1973) is

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* In urban areas, a complete photochemical mechanism should be applied to calculate NO_2 concentrations. Also, it should be noted that NO_2 is destroyed by reaction with the hydroxyl radical (OH•), as discussed in the next subsection.

$$\frac{d[NO_2]}{dt} = \left[4.015 \times 10^{-12} \exp\left(\frac{1046}{RT}\right)\right][NO]^2[O_2] \text{ ppm/s} \quad . \qquad (23)$$

where R is the universal gas constant and T is the absolute temperature.

The reaction with ozone also affects the conversion of NO to NO_2:

$$NO + O_3 \rightarrow NO_2 + O_2 \quad . \qquad (24)$$

The reaction is fast, with a rate (Leighton, 1961; Davis, Smith, and Klauber, 1974; Niki, 1974) at 25°C of

$$\frac{d[NO_2]}{dt} = 0.44\ [NO][O_3] \text{ ppm/s} \quad . \qquad (25)$$

This reaction accounts for the ozone depletion measured within power plant plumes and is important because ozone concentrations can be high even in nonurban regions. Measured ozone concentrations in nonurban areas of the western United States range from 0.02 to 0.08 ppm.

Whereas the thermal oxidation rate in reaction (23) decreases as the plume mixes (because the NO concentration decreases), the formation of nitrogen dioxide via equation (24) is enhanced as the plume mixes because additional ozone from the atmosphere is mixed into the plume, allowing equation (24) to proceed. When there are no reactions converting NO_2 to NO (e.g., at night), equation (24) proceeds until all of the NO in the plume is converted to NO_2 or until the ozone concentration in the plume drops to zero. Therefore, the rate of conversion of NO to NO_2 via equation (24) is limited by the rate of plume mixing that provides the necessary atmospheric ozone.

To complete the set of chemical reaction mechanisms, we must consider the photolysis of NO_2. When sunlight illuminates a plume containing nitrogen dioxide, short wavelength light and ultraviolet radiation are absorbed by the NO_2. As noted above, absorption of the shorter wavelength light produces the characteristic yellow-brown color associated with NO_2. Absorption of the more energetic ultraviolet light (UV) results in dissociation of the NO_2 molecule:

$$NO_2 + h\nu \rightarrow NO + O \quad . \qquad (26)$$

$$O + O_2 \rightarrow O_3 \quad . \qquad (27)$$

Leighton (1961) gave the rate of reaction (26) as

$$\frac{d[NO_2]}{dt} = -K_d\ [NO_2]\ \text{ppm/s} \quad , \tag{28}$$

where K_d depends on the amount of light incident on the nitrogen dioxide. Davis, Smith, and Klauber (1974) gave the following expression for K_d as a function of the solar zenith angle Z_s:

$$K_d = 1 \times 10^{-2} \exp\left(-\frac{0.38}{\cos Z_s}\right) s^{-1} \quad . \tag{29}$$

With this set of chemical reactions, the chemical conversion of NO to NO_2 in the atmosphere can be calculated from background pollutant concentrations and from plume NO_x increments using the technique suggested by Latimer and Samuelsen (1975) and White (1977). Making the steady-state approximation, we have

$$[NO_2] = \frac{K_r}{K_d}[NO][O_3] \quad , \tag{30}$$

where

$$[NO] = [NO_x] - [NO_2] \tag{31}$$

and

$$[O_3] = [O_3]_b - [NO_2] - [NO_2]_t - [NO_2]_b \quad , \tag{32}$$

where $[NO_2]t$ signifies the concentration of NO_2 formed via the termolecular reaction (22) and $[NO_2]b$ signifies background concentrations. Substituting equations (28) and (29) into equation (27) we can solve for the concentration of NO_2:

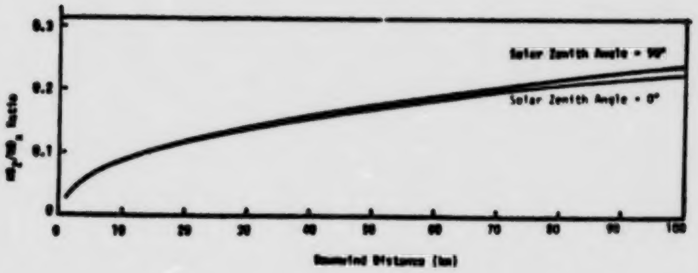
$$[NO_2] = 0.5 \left\{ [NO_x] + [O_3]_b + [NO_2]_t + [NO_2]_b + \frac{K_d}{K_r} - \left[\left([NO_x] + [O_3]_b + [NO_2]_t + [NO_2]_b + \frac{K_d}{K_r} \right)^2 - 4[NO_x] \left([O_3]_b + [NO_2]_t + [NO_2]_b \right) \right]^{1/2} \right\} . \tag{33}$$

Using this formulation to compute NO-to-NO_2 conversion in a hypothetical power plant plume, Latimer and Samuelsen (1978) studied the sensitivity of NO_2 formation to the rate of plume dilution, background ozone concentration, and solar radiation. The results of this analysis are presented in figure 3. This figure shows that thermal oxidation (e.g., $[O_3] = 0$) converts up to 10 percent of the plume NO to NO_2, and additional conversion results when ambient ozone is mixed into the plume. A recent comparison of observations with calculations using equation (33) indicates good agreement, particularly if the diffusion of the plume is correctly calculated by using fitted diffusion coefficients based on plume diffusion measurements (see figure 4).

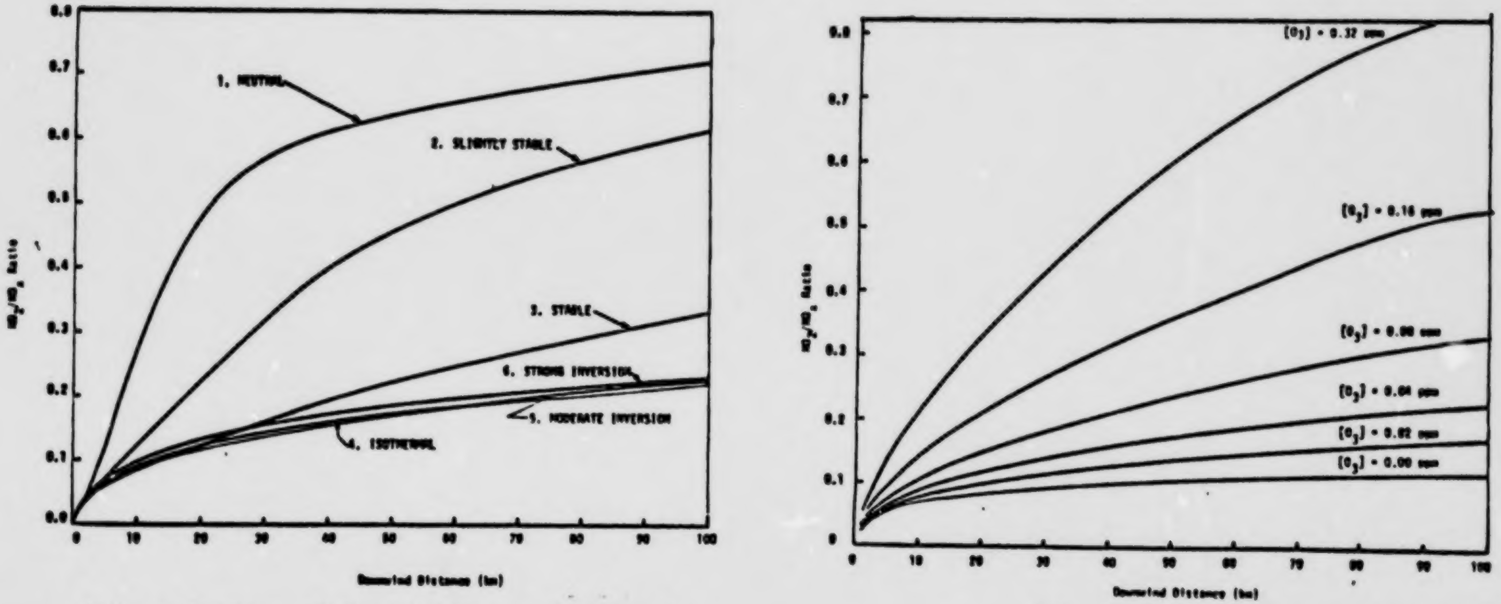
Conversion of SO_2 to $SO_4^=$

It is critical to calculate the conversion of SO_2 emissions to sulfate ($SO_4^=$) aerosol, because the latter can effectively scatter light and cause reductions in visual range. The importance of SO_2 to$SO_4^=$ conversion can be seen from the schematic logic flow shown in figure 1. The usual approach is to assume that sulfur dioxide (SO_2) gas is converted to sulfate ($SO_4^=$) aerosol at some constant rate; this approach employs a user-input value of a pseudo-first-order rate constant whose value is empirically determined.

There is considerable variation, however, in such measured SO_2-to-$SO_4^=$ conversion rates, which range from a few tenths of a percent to several percent per hour. Much of this variance in SO_2-to-$SO_4^=$ conversion observed in field measurement programs in recent years can be explained using a model that accounts for the reactions of plume SO_2 and NO_2 with the hydroxyl (OH•) radical. This chemical mechanism is incorporated in



(a) Solar radiation



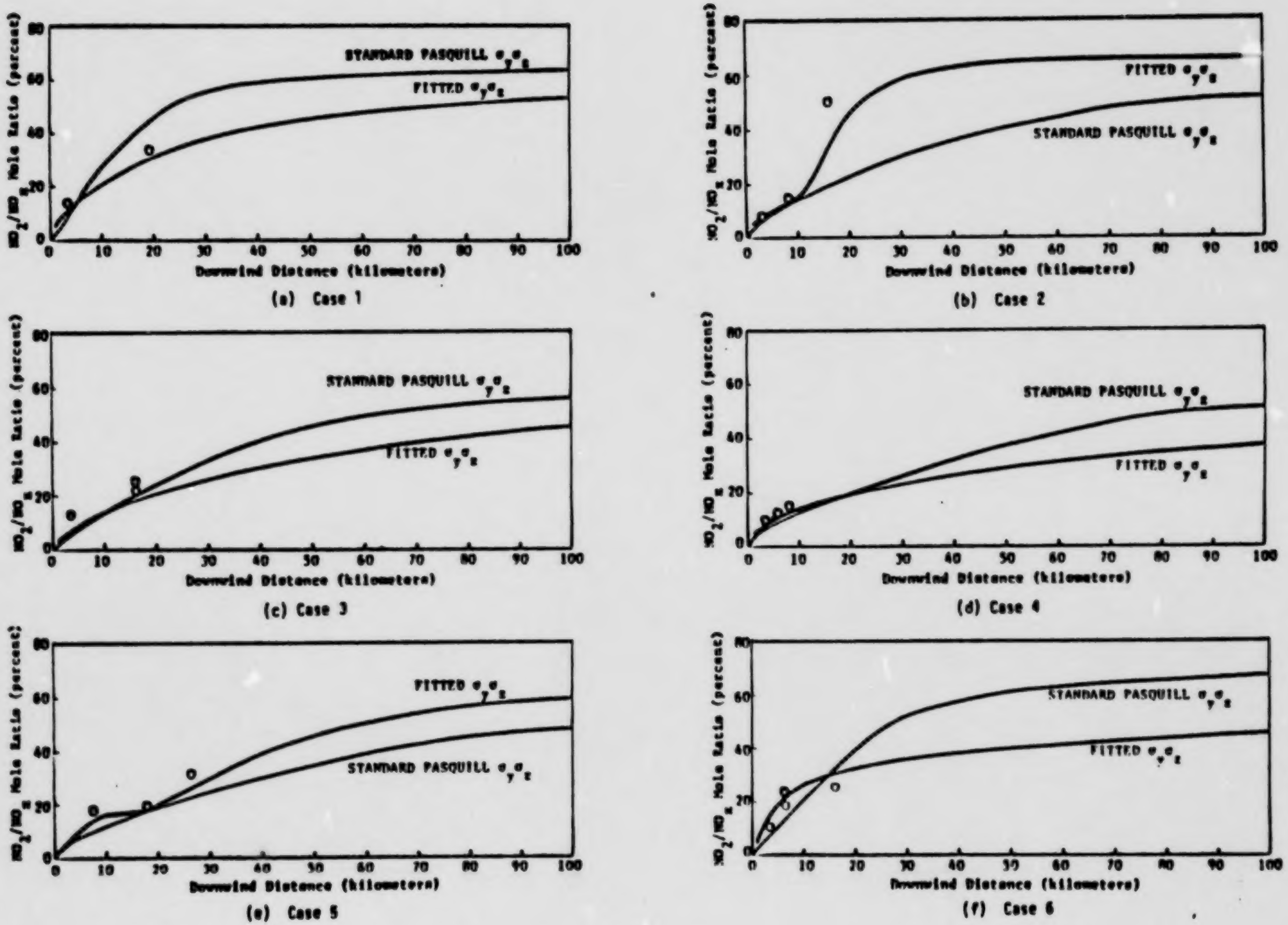
(b) Stability (TVA stability categories)

(c) Background ozone

Reproduced from best available copy.

Source: Latimer and Samuelsen (1978).

Figure 3. Sensitivity of NO-to-NO_2 conversion in power plant plumes to the rate of plume dilution, background ozone concentration, and solar radiation.



(a) Case 1

(b) Case 2

(c) Case 3

(d) Case 4

(e) Case 5

(f) Case 6

Figure 4. Comparison of measured NO_2/NO_x mole ratios (circled points) in the plume centerline downwind of a coal-fired power plant with computer-calculated values (solid lines) using standard Pasquill and fitted $\sigma_y\sigma_z$.

PLUVUE II. In clean background areas, the gas-phase oxidation of SO_2 and NO_2 to sulfate aerosol and nitrate (nitric acid vapor) is due primarily to the reaction of these species with OH·. Previous assessments of homogeneous (gas-phase) oxidation of SO_2 to sulfate estimated the proportion assignable to the reaction with hydroxyl between about 75 percent in clean atmospheres (Calvert et al., 1978; Altshuller, 1979) and as low as 40 percent in polluted urban air (Isaksen, Hesstredt, and Hov, 1978), but more recent estimates place these values much higher. Kinetic models forming the basis of the early estimates used the value of $1.3 \times 10^{-12} cm^3 mol^{-1} s^{-1}$ for the rate constant of reaction for HO_2 and CH_3O_2 with NO. More recently, however, this rate has been measured at $8.1 \times 10^{-12} cm^3 mol^{-1} s^{-1}$ (Hampson and Garvin, 1978). This larger rate constant lowers the expected concentration of these peroxy radicals by a factor of 6 and, in turn, greatly reduces the SO_2 conversion resulting from reactions with these radicals. When recalculated using the new rate constant, the fraction of SO_2-to-sulfate conversion that results from reaction with the hydroxyl radical is approximately 95 percent for clean atmospheres and 70 percent for the extremely polluted case.

These estimates are supported by the work of Miller (1978), who found that the SO_2 oxidation rate was not dependent on the absolute concentrations of hydrocarbons and nitrogen oxides but on the ratio of nonmethane hydrocarbon to nitrogen oxides.

The rate of sulfate (and nitric acid) formation can be estimated by calculating the steady-state concentration of OH· within a plume. This steady-state plume OH· concentration is calculated by balancing the rate of OH· production with the rate of OH· destruction. The following reactions are used:

> OH· production*

- $O_3 + h\nu \rightarrow O('D) + O_2$

$$\left[\left(K_{34} = 1.3 \times 10^{-3} (\cos Z_s)^{2.74} \mathrm{min}^{-1}\right)\right] \qquad (34)$$

- $O('D) + M \rightarrow O(^3P) + M \; (K_{35} = 4.45 \times 10^{10} \mathrm{min}^{-1})$ (35)

---

* See Latimer et al. (1980) for a discussion of other sources of OH·. Rate constants are based on Whitten and Killus (1980), private communication.

- $O('D) + H_2O \rightarrow 2\ OH\cdot$ ($K_{36} = 3.4 \times 10^5 ppm^{-1} min^{-1}$) (36)

> OH• destruction (major sinks in plumes)

- $OH\cdot + SO_2 \rightarrow HSO_3 \ldots$ ($K_{37} = 2.0 \times 10^3 ppm^{-1} min^{-1}$) (37)

- $OH\cdot + NO_2 \rightarrow HNO_3$ ($K_{38} = 1.4 \times 10^4 ppm^{-1} min^{-1}$) . (38)

With the assumption of steady-state concentrations of O('D) and OH• in the plume, we can write the following equations:

$$\frac{d[OH\cdot]}{dt} = \frac{d[O'(D)]}{dt} = 0 \quad , \tag{39}$$

$$\frac{d[O('D)]}{dt} = K_{34}(h\nu)[O_3] - K_{35}[O('D)] - K_{36}[O'(D)][H_2O] \quad , \tag{40}$$

$$[O('D)] = \frac{K_{34}(h\nu)[O_3]}{K_{35} + K_{36}[H_2O]} \quad , \tag{41}$$

$$\frac{d[OH\cdot]}{dt} = 2\ K_{36}[O('D)][H_2O] - K_{37}[OH\cdot][SO_2] - K_{38}[OH\cdot][NO_2] \quad , \tag{42}$$

$$[OH\cdot] = \frac{2\ K_{36}[O('D)][H_2O]}{K_{37}[SO_2] + K_{38}[NO_2]} \quad . \tag{43}$$

With this steady-state concentration, plume pseudo-first-order SO_2-to-SO_4 and NO_2-to-HNO_3 conversion rates can be calculated as follows:[*]

$$-\frac{1}{[SO_2]}\frac{d[SO_2]}{dt} = K_{37}[OH\cdot] \quad , \tag{44}$$

$$-\frac{1}{[NO_2]}\frac{d[NO_2]}{dt} = K_{38}[OH\cdot] \quad . \tag{45}$$

Note from equations (41) and (42) that plume OH• concentrations are reduced below background tropospheric values for two reasons:

> Plume ozone (O_3) concentrations are reduced below background values because of the reaction $NO + O_3 \rightarrow NO_2 + O_2$ (eq. 24).

> Plume concentrations of NO_2 and SO_2 are high, thus reducing steady-state OH• concentrations.

It should be pointed out that at night there is no production of OH• from ozone photolysis; also, in early morning and late afternoon and in winter OH• production is diminished because ultraviolet flux decreases as solar zenith angles approach 90°. Thus, sulfate and nitrate are not formed at night and are formed only very slowly in concentrated plumes. Nitrate is expected to remain as HNO_3 vapor and without visual effects until it is eventually deposited. Ammonium nitrate could exist in aerosol form; however, sulfate competes for available atmospheric ammonia.

PLUVUE was run, with this OH• chemical mechanism included, for a plume from a 1600 Mwe coal-fired power plant. On the basis of this case study, the effect of the following on sulfate formation rate was studied:

> Plume dilution, corresponding to neutral and stable light-wind conditions at various downwind distances.

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[*] The user is given the option in PLUVUE II of supplementing the SO_2-to-$SO_4^{=}$ conversion rate calculated on the basis of steady-state plume OH• concentrations with a user-input pseudo-first-order rate constant, which can be varied as a function of downwind distance.

> Time of day.

> Season.

The history of sulfate formation in a plume parcel based on this case study is shown in figure 5. Note that time of day, season, and plume concentration all affect the rate of sulfate formation. This effect is explained by the formulations shown in equations (41), (43), and (44).* The SO_2-to-$SO_4^=$ conversion rate is directly proportional to the plume ozone and water vapor concentrations and to ultraviolet (UV) flux, and it is inversely proportional to plume SO_2 and NO_2 concentrations.

The effect of UV flux is noted in both the seasonal and time-of-day dependence of the sulfate formation rate. Note from figure 5 that no conversion of SO_2 to sulfate occurs at night. Sulfate formation starts after sunrise, reaches its maximum rate at noon (when ultraviolet flux reaches a maximum), and then begins to decrease. Thus, a plume parcel observed at a given distance downwind from a power plant may have undergone sulfate formation during only a fraction of its journey. For example, a plume parcel 160 km downwind of its source, when winds are 2 m/s, would require a transit time of more than 22 hours. During this period sulfate would be formed only during the sunlight hours [see figure 5(b)].

The effect of plume SO_2 and NO_2 concentrations on the steady-state OH• concentration and hence on sulfate formation is also shown in figure 5. Note, by comparing figure 5(a) with 5(b), that sulfate formation is much more rapid when plume parcels are more dilute (at farther downwind distances). In the dilute, neutral-stability plumes at downwind distances greater than 100 km, sulfate formation rates reach noon peaks of about 0.06, 0.02, and 0.004 percent per hour, respectively, for the summer, fall, and winter simulations for this latitude. In the less dilute, neutral-stability plumes at downwind distances of less than 100 km, the sulfate formation rates peak at 0.016, 0.008, and less than 0.002 percent per hour for summer, fall, and winter, respectively. However, formation rates in stable plumes are considerably less than 0.01 percent per hour even at noon on a summer day.

These model calculations support the argument made by Latimer (1980) that the atmospheric discoloration of stable power plant plumes (where particulate emissions are controlled) is caused primarily by nitrogen

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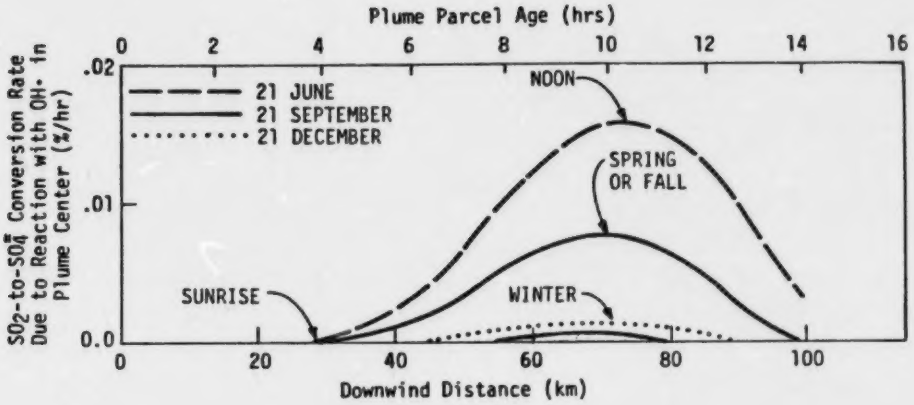
* It should be noted that sulfate can form not only by reactions with OH• but also on existing, catalytic fly ash particles. However, this sulfate coating on existing particles is not expected to significantly add to aerosol surface area, which is important for light scattering.



Notes:

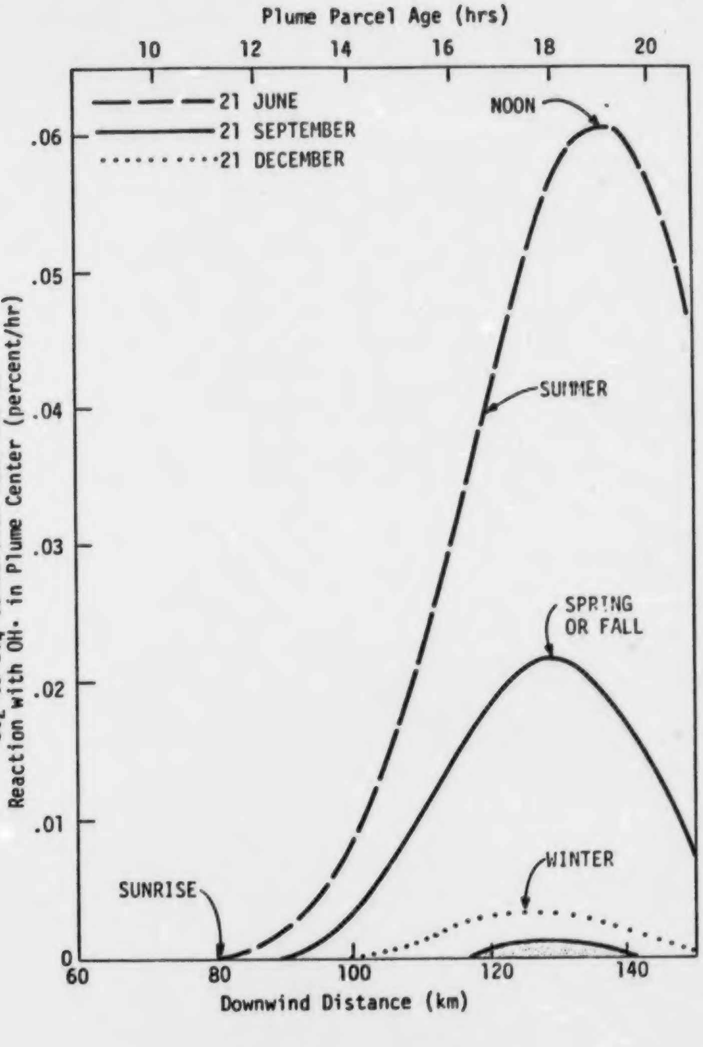
(1) Time-dependent SO_2-to-$SO_4^=$ conversion rates for the history of a parcel in the center of a well-mixed plume (neutral stability) which is observed 100 km downwind at 1500 (in the afternoon) are plotted for indicated seasons in Figure 5(a).

(2) Comparable conversion rates for a well-mixed plume observed 160 km downwind at 1500 are plotted in Figure 5(b).

(3) Conversion rates for stable plumes (isothermal stability) are considerably less than 0.01 percent/hr. See shaded areas at the bottom of graphs.

(a) Life history of a plume parcel observed 100 km downwind at 1500 hours.

Figure 5. Calculated time dependence of sulfate formation in the center of plumes from a 1600 Mwe coal-fired power plant, 2 m/s winds, neutral and stable conditions



(b) Life history of a plume parcel observed 160 km downwind at 1500 hours.

Figure 5 (concluded)

dioxide (NO_2) gas, not by secondary sulfate aerosol. Sulfate aerosol is not formed in plumes during nighttime transport, and formation is minimal during daytime transport when plumes are concentrated (as they would be during stable conditions). After plumes have become well mixed, significant rates of sulfate formation can occur in the daytime, though these rates approach zero with low sun angles. Thus, sulfate formation is a long range (greater than 100 km), multiday phenomenon, not a near-source problem.

AEROSOL SIZE DISTRIBUTION

The aerosol size distribution is characterized by a series of aerosol modes, each having a log-normal distribution of mass (or volume). Each of the following modes is treated separately in PLUVUE:

- Background accumulation mode (submicron) aerosol (typically having a mass median diameter of about 0.3 μm and a geometric standard deviation of 2).
- Background coarse mode (> 1 μm) aerosol (typically having a mass median diameter of about 6 μm and a geometric standard deviation of 2).
- Background carbonaceous aerosol (typically having a mass median diameter of about 0.1 μm and a geometric standard deviation of 2).
- Plume primary particulate aerosol (e.g., fly ash emissions).
- Plume secondary sulfate ($SO_4^=$) aerosol (typically having a mass median diameter of 0.1 to 0.3 μm and a geometric standard deviation of 2).
- Plume carbonaceous aerosol (typically having a mass median diameter of 0.1 μm and a geometric standard deviation of 2).

The expression developed by Winkler (1973) is used to calculate the amount of liquid water associated with submicron background and plume sulfate aerosol as a function of relative humidity.

Secondary aerosol is assumed to form in the submicron plume secondary aerosol mode. A time delay equal to the time between successive downwind distances is introduced to account for coagulation and condensation time delays.

ATMOSPHERIC OPTICS

In the atmospheric optics component of the plume visibility model, the light scattering and absorption properties of the aerosol and the resultant light intensity (spectral radiance) for various illumination and viewing situations are computed.

Calculation of the Scattering and Absorption Properties

After the concentrations of the pollutants are specified by the transport and chemistry subroutines, their radiative properties must be determined. For NO_2, the absorption at a particular wavelength is a tabulated function (Nixon, 1940) multiplied by the concentration. For aerosols, however, the procedure is more complicated.

In general, a particle's ability to scatter and absorb radiation at a particular frequency is a function of size, composition, shape, and relative humidity. The flexibility to specify the size distribution of both primary and secondary particles was desired. Therefore, the effect of particle size on the wavelength dependence of the extinction coefficient and the phase function, the solution of Maxwell's equations for scattering by a sphere, and the so-called Mie equations were used in PLUVUE II. These calculations are appropriate for atmospheric aerosol; comparisons of Mie calculations, with empirical correlations of scattering-to-mass indicate substantial agreement.

The Mie calculations in PLUVUE II are performed using an IBM subroutine written by J. V. Dave (Dave, 1970). The required inputs are the particle size parameter (ratio of the circumference to the wavelength of radiation), the index of refraction (real and imaginary part), and the number and location of absorption cross sections and the Stokes transformation matrix (Van De Hulst, 1957), which can be simply converted to the scattering distribution assuming randomly polarized light. The scattering and absorption properties per particle are then summed over the particular log-normal size distribution for the given aerosol mode.

Calculation of Light Intensity

The light intensity, or radiance (watts/m^2/steradian) at a particular location in the atmosphere is a function of the direction of observation Ω and the wavelength λ. Calculation of the light intensity in a medium follows from the radiative transfer equation. This equation is a conservation of energy statement that accounts for the light added to the line of sight by scattering and the light lost because of absorption and scattering. Approximations and solution techniques applicable to planetary atmospheres have been discussed by Hansen and Travis (1974) and Irvine (1975).

The physical situation that we are concerned with is shown schematically in figure 6. To compute the spectral light intensity at the observer, we sum (integrate) the scattered and absorbed light over the path, r, associated with the line of sight Ω. The resultant general expression for the background sky intensity at a particular wavelength is

$$I_b(\Omega) = \int_0^{\tau_\infty} \frac{\omega(\tau)}{4\pi} \int_{\Omega'=4\pi} I(\Omega',\tau')p(\Omega'\to\Omega,\tau')\, d\Omega'\, e^{-\tau'}\, d\tau' \quad , \qquad (46)$$

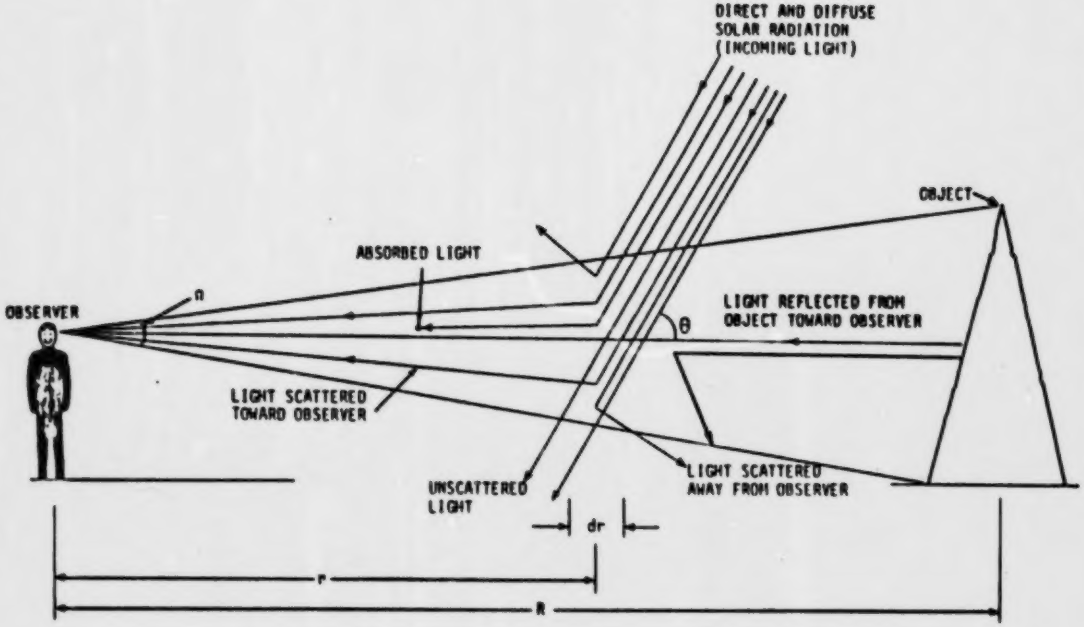
where

τ = the optical depth ($\tau \equiv \int_0^r b_{ext}\, dr$, where b_{ext} is the extinction coefficient),
ω = the albedo for single scattering ($\omega \equiv b_{scat}/b_{ext}$ where b_{scat} is the scattering coefficient),
$p(\Omega' \to \Omega)$ = the scattering distribution function for the angle $\Omega' \to \Omega$),
I = the spectral intensity at τ' from direct and diffuse solar radiation.

The intensity seen by an observer in direction Ω of a background viewing object of intensity I_o at distance R is

$$I_{obj}(\Omega) = I_o(\Omega)e^{-\tau_R} + \int_0^{\tau_R} \frac{\omega(\tau')}{4\pi} \int_{\Omega'=4\pi} I(\Omega',\tau)\, p(\Omega' \to \Omega,\tau')\, d\Omega'\, e^{-\tau'}\, d\tau' \quad . \qquad (47)$$

Equations (46) and (47) then completely describe the spectral intensity of the sky and a background object. Once these two quantities



DIRECT AND DIFFUSE SOLAR RADIATION (INCOMING LIGHT)
OBJECT
ABSORBED LIGHT
LIGHT REFLECTED FROM OBJECT TOWARD OBSERVER
OBSERVER
Ω
θ
LIGHT SCATTERED TOWARD OBSERVER
UNSCATTERED LIGHT
LIGHT SCATTERED AWAY FROM OBSERVER
dr
r
R

Figure 6. Light scattering and absorption in the atmosphere.

are known, the visual effects of the intervening atmosphere can be quantified. In evaluating equations (46) and (47), we encounter two main difficulties: First, the quantity in the integral is a fairly complicated function, and accurate specification is tedious. Second, the atmosphere is inherently inhomogeneous; thus, the radiative properties ω, p are somewhat complicated functions of r and Ω. The following approximations are therefore made in PLUVUE II:

- > Plane parallel atmosphere
- > Two homogeneous layers
- > Average solar flux approximation

The equation for the background intensity at the surface becomes, for a given viewing direction,

$$I_b(\Omega) = I_\infty(\Omega)\, e^{-\tau_\infty} + F_s \int_0^{\tau_\infty} \frac{\omega(\tau')}{4\pi}\, e^{-\tau_z/\mu_s}\, P(\Omega_s \to \Omega, \tau')\, e^{-\tau'} d\tau'$$

$$+ \int_0^{\tau_\infty} \frac{\omega(\tau')}{4\pi} \int_{\Omega'=4\pi} I(\Omega',\tau')\, P(\Omega' \to \Omega, \tau')\, d\Omega'\, e^{-\tau'} d\tau' \quad . \qquad (48)$$

The atmosphere is then assumed to be composed of two layers of homogeneous properties, i.e., an upper atmospheric layer and a planetary boundary layer (Bergstrom and Viskanta, 1974).

The radiance impinging on the top of the planetary boundary layer, $I_{sky}(\Omega)$, is calculated from average properties of the upper atmospheric layer.

$$I_{sky}(\Omega) = \frac{\bar{\omega}_\infty}{4\pi}\, \bar{P}_\infty(\theta_s)\, F_s \int_{\tau_L}^{\tau_\infty} e^{-\tau_z/\mu_s}\, e^{-\tau'} d\tau' \quad , \qquad (49)$$

where $\bar{\omega}_\infty$ and $\bar{P}_\infty(\theta_s)$ are average albedo and phase functions, respectively, and τ_L is the optical depth of the planetary boundary layer. Equation (48) is then rewritten as follows:

$$I_b(\Omega) = I_{sky}(\Omega)\, e^{-\tau_L} + F_s \int_0^{\tau_L} \frac{\omega(\tau')}{4\pi}\, e^{-\tau_z/\mu_s}\, P(\Omega' \to \Omega, \tau')\, e^{-\tau'} d\tau'$$

$$+ \int_0^{\tau_\infty} \frac{\omega(\tau')}{4\pi} \int_{\Omega'=4\pi} I(\Omega',\tau')\, P(\Omega' \to \Omega, \tau')\, d\Omega'\, e^{-\tau'} d\tau' \quad . \qquad (50)$$

In Equations (48) and (50), the first term represents the light that travels directly from the object to the observer, the second term is integrated along the line of sight and represents the light that has been scattered once from the sunlight's angle of incidence into the line of sight (single-scattering term), and the third term represents the light that has been scattered at least once before being scattered into the line of sight (multiple-scattering term).

The first term is calculated from the values of the background object radiance or sky radiance at the top of the boundary layer and extinction coefficient. The background object radiance, $I_o(\Omega)$, is calculated from the optical depth and from the molecular and aerosol scattering phase functions. Since the sky radiance, $I_{sky}(\Omega)$, is given by Equation (49), it depends on the aerosol concentration and size distributions, and on the scattering angle.

For the second term, one assumes spatially averaged albedo $\bar{\omega}$ and phase functions $P(\theta_s)$ for the planetary boundary layer. Equation (47) may be rewritten as follows:

$$I_{obj}(\Omega) = I_o(\Omega)\, e^{-\tau_R} + F_s \frac{\bar{\omega}}{4\pi} P(\theta_s) \int_0^{\tau_R} e^{-\tau_z/\mu_s}\, e^{-\tau'} d\tau' + G(\Omega,\tau_R) \quad , \tag{51}$$

where θ_s is the single-scattering angle and $G(\Omega,\tau_R)$ is the multiple-scattering term. The second term is calculated from the values of the extinction coefficient along the line of sight. Similarly, Equation (50) is rewritten as follows:

$$I_b(\Omega) = I_{sky}(\Omega)\, e^{-\tau_L} + F_s \frac{\bar{\omega}}{4\pi} P(\theta_s) \int_0^{\tau_L} e^{-\tau_z/\mu_s}\, e^{-\tau'} d\tau' + G(\Omega,\tau_\infty) \quad . \tag{52}$$

The radiance of a plume with a background object is calculated in three steps, as shown schematically in Figure 7. First, the background radiance incident on the plume, $I_1(\Omega)$, is calculated according to Equation 53:

$$I_1(\Omega) = I_o(\Omega)\, e^{-\tau_1} + F_s \frac{\bar{\omega}}{4\pi} P(\theta_s) \int_0^{\tau_1} e^{-\tau_z/\mu_s}\, e^{-\tau'} d\tau' + G(\Omega,\tau_1) \quad , \tag{53}$$

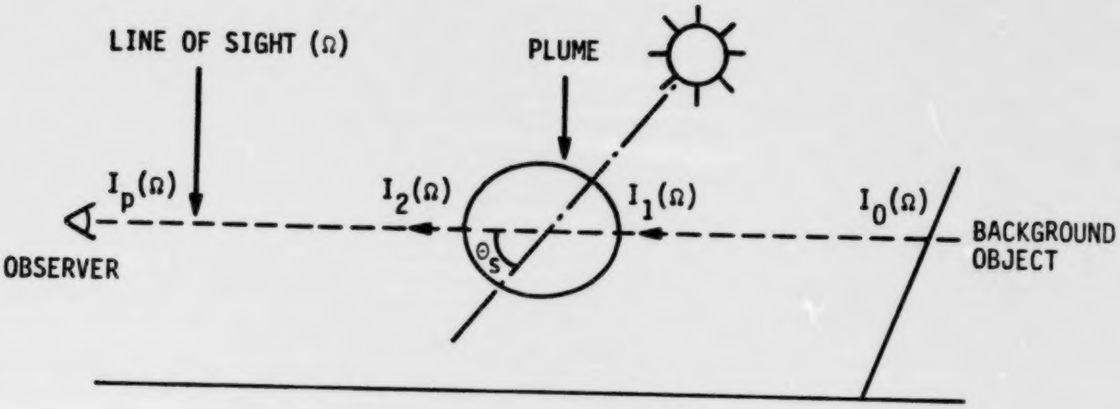

LINE OF SIGHT (Ω)
PLUME
$I_p(\Omega)$
$I_2(\Omega)$
$I_1(\Omega)$
$I_0(\Omega)$
OBSERVER
Θ_s
BACKGROUND OBJECT

Figure 7. Schematic representation of the plume radiance calculations.

where τ_1 is the optical depth between the background object and the observer.

The radiance leaving the plume, $I_2(\Omega)$, is calculated from $I_1(\Omega)$ and the scattering and absorption of light in the plume:

$$I_2(\Omega) = I_1(\Omega)\, e^{-\tau_p} + F_s \frac{\bar{\omega}_p}{4\pi} P(\theta_s) \int_0^{\tau_p} e^{-\tau_z/\mu_s}\, e^{-\tau'} d\tau' + G(\Omega,\tau_p) \quad , \tag{54}$$

where τ_p is the optical depth of the plume along the line of sight, and $\bar{\omega}_p$ the plume albedo. These variables are calculated from the plume gas and particle scattering and absorption coefficients. The integration of these coefficients is carried out by assuming that the plume is Gaussian (Latimer and Samuelsen, 1978).

The plume radiance at the observer location, $I_p(\Omega)$, is then calculated from $I_2(\Omega)$ according to Equation (55):

$$I_p(\Omega) = I_2(\Omega)\, e^{-\tau_2} + F_s \frac{\bar{\omega}}{4\pi} P(\theta_s) \int_0^{\tau_2} e^{-\tau_z/\mu_s}\, e^{-\tau'} d\tau' + G(\Omega,\tau_2) \quad , \tag{55}$$

where τ_2 is the optical depth between the plume and the observer.

The contrast of the plume can then be calculated from the plume and background radiances as follows:

$$c = \frac{I_p(\Omega) - I_{obj}(\Omega)}{I_{obj}(\Omega)} \quad . \tag{56}$$

In calculating the radiances, the multiple-scattering term requires the integration of the angle-dependent sky radiance over all angles and over the optical depth. The calculation is performed in two steps that are summarized as follows.

First, the scattered intensity source function is calculated according to the algorithm of Isaacs (1981a, Appendix D). The formulation is based on a two-stream approximation to the radiative transfer equation and employs the Rayleigh and Henyey-Greenstein phase functions for molecular and aerosol scattering, respectively. The phase functions are calculated according to Mie theory. Then, the multiple-scattering term is calculated by integrating over Ω' and τ'. This approach allows an anisotropic description of the multiple-scattering term that is computationally reasonable.

Thus, the background intensity and the intensity in the direction of an object at distance R from the observer can be computed given the following inputs:

- Background radiative properties (e.g., size distribution, visual range).
- Solar zenith angle.
- Scattering angle.
- Viewed object intensity.
- Direction of observation.
- Planetary boundary layer height.

The plume is treated as a homogeneous layer with a given optical thickness and mean properties $\overline{\omega}_{plume}$ and $\overline{p}_{plume}(\Theta)$. We also assume that the plume does not affect the solar radiation illumination (an optically thin plume).

Spectral radiance, or light intensity $I(\lambda)$, is calculated for 39 wavelengths spanning the visible spectrum ($0.36\ \mu m < \lambda < 0.74\ \mu m$, in 0.01 μm increments).

GEOMETRY OF PLUME, OBSERVER, AND SUN

For performing as many as four different types of optics calculations at selected points along the plume trajectory, PLUVUE has two modes: plume-based and observer-based calculations. The calculations for plume transport, diffusion, and chemistry are identical for calculations in both modes. The major difference between the two types of calculations is the orientation of the position of the viewer to the source and the plume.

Plume-based calculations are repeated for several combinations of plume-observer-sun geometries. Because of the repetitions, these plume-based calculations are more expensive and produce more printed output than the observer-based calculations, which are performed for only the specific line-of-sight orientations corresponding to the given observer position, the portions of the plume being observed, and the specific position of the sun relative to these lines of sight.

There are four types of optics calculations: (1) horizontal views through the plume with a sky viewing background; (2) nonhorizontal views through the plume with a sky viewing background; (3) horizontal views through the plume with white, gray, and black viewing backgrounds; and (4) horizontal views along the axis of the plume with a sky viewing background.

Figure 8a illustrates the geometry of the plume-based optics calculations for horizontal views through the plume. This figure depicts schematically the variety of distances from the observer to the plume and the variety of horizontal azimuthal angles between the line of sight and the plume trajectory.* Calculations for all these geometries are repeated for up to six different scattering angles.

Plume-based calculations for nonhorizontal views through the plume are shown in figures 8b and 8c. For one azimuthal angle (α), figure 8b shows the range of vertical elevation angles (β) of the line of sight. The observer position is determined by the intersection of the line of sight with flat terrain. For one elevation angle (β) of the line of sight, figure 8c shows the range of four azimuthal angles (α) between the plume centerline and the line of sight. Again, these calculations are repeated for as many as six different scattering angles at each point of analysis along the plume trajectory.

Figure 9 shows the geometry for the optics calculation for horizontal views perpendicular to the plume with white, gray, and black viewing backgrounds. For each point on the plume trajectory and each scattering angle, the calculations are executed for a range of distances from the observer to the background object, starting at the plume centerline and ending at 80 percent of the background visual range. The distances, from the observer to the plume, range from 2 percent to 80 percent of the background visual range.

Figure 10 illustrates the configuration used for the plume-based calculation for views along the axis of the plume. The calculations are made from the second through the final downwind distances. At each point, the observer is looking toward the emissions source with a sky background. The calculations are made for views through plume segments defined by the

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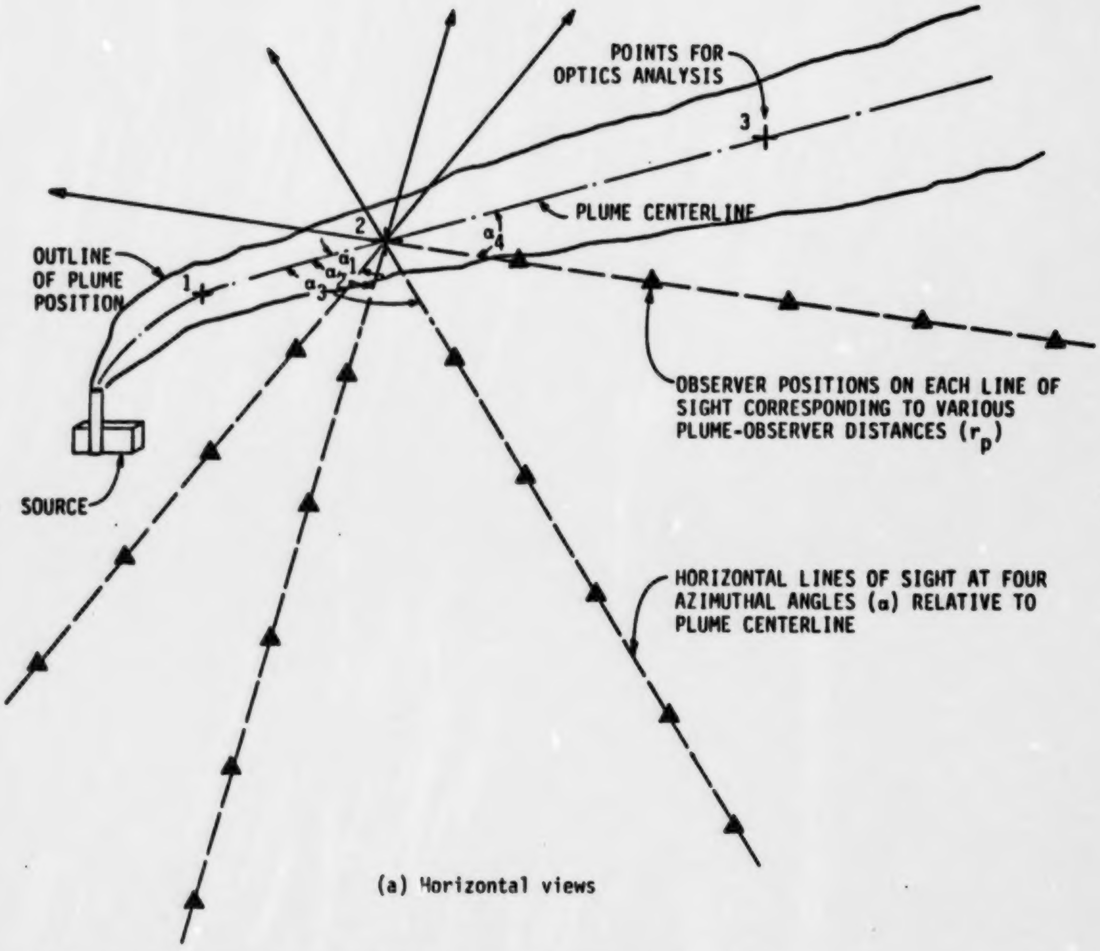
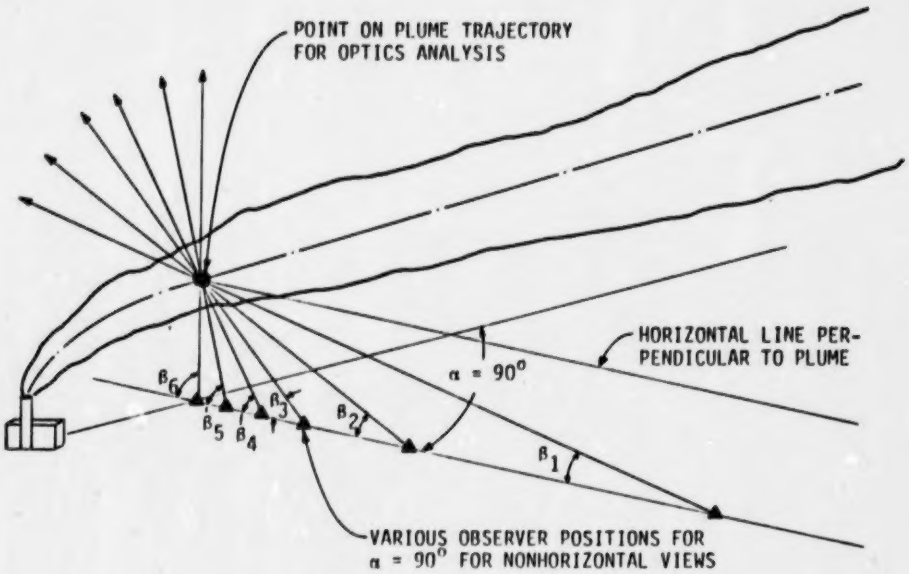
* These azimuthal angles are measured from the plume centerline to the line of sight such that the angles range from 0° to 90°.


POINTS FOR
OPTICS ANALYSIS
3
2
1
PLUME CENTERLINE
OUTLINE
OF PLUME
POSITION
α_1
α_2
α_3
α_4
SOURCE
OBSERVER POSITIONS ON EACH LINE OF
SIGHT CORRESPONDING TO VARIOUS
PLUME-OBSERVER DISTANCES (r_p)
HORIZONTAL LINES OF SIGHT AT FOUR
AZIMUTHAL ANGLES (α) RELATIVE TO
PLUME CENTERLINE

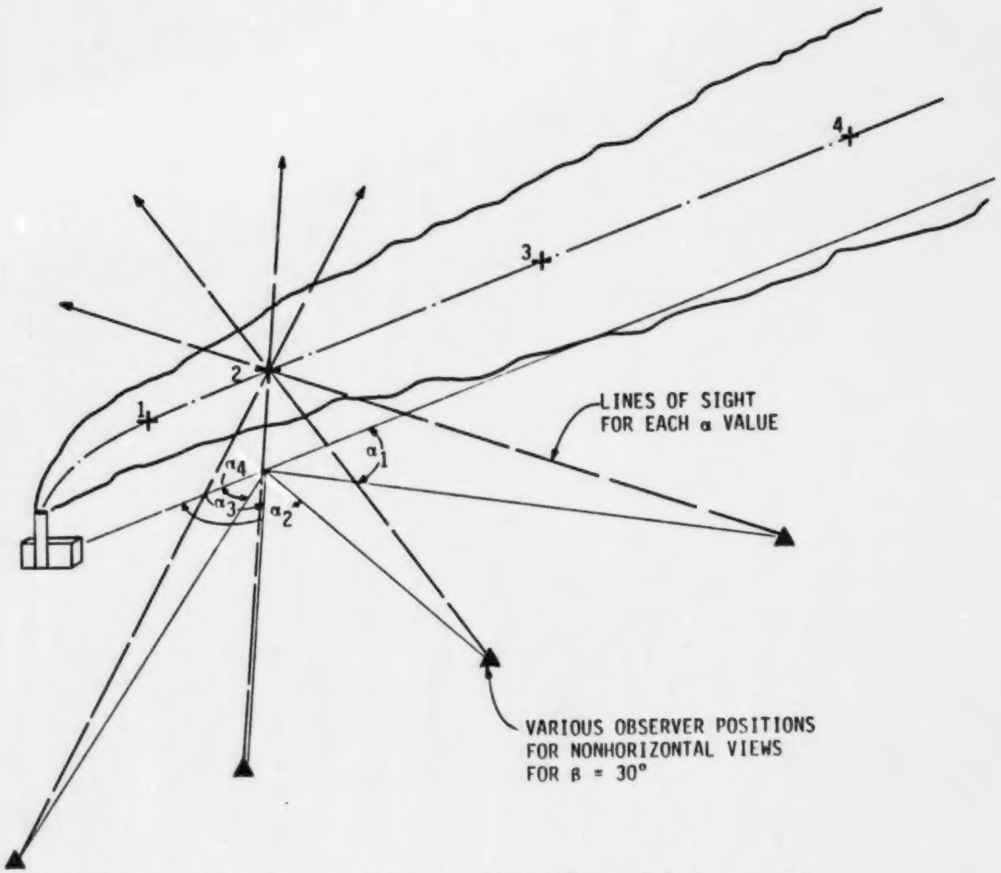
(a) Horizontal views

Figure 8. Geometries for plume-based calculations with a sky background.


POINT ON PLUME TRAJECTORY
FOR OPTICS ANALYSIS
HORIZONTAL LINE PER-
PENDICULAR TO PLUME
α = 90°
β1
β2
β3
β4
β5
β6
VARIOUS OBSERVER POSITIONS FOR
α = 90° FOR NONHORIZONTAL VIEWS

(b) Nonhorizontal views, variation in elevation angle (β) for a fixed azimuthal angle (α = 90°) between the plume trajectory and the line of sight.

Figure 8 (continued)


LINES OF SIGHT
FOR EACH α VALUE
VARIOUS OBSERVER POSITIONS
FOR NONHORIZONTAL VIEWS
FOR β = 30°
1
2
3
4
α_1
α_2
α_3
α_4

(c) Nonhorizontal views, variation in azimuthal angle (α) for a fixed elevation angle (β = 30°).

Figure 8 (concluded).

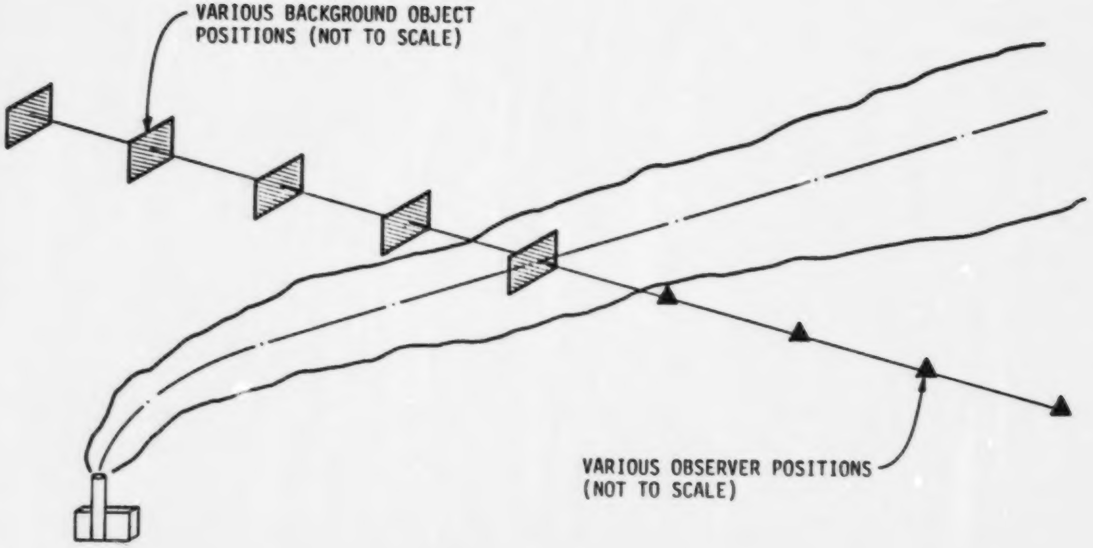

VARIOUS BACKGROUND OBJECT POSITIONS (NOT TO SCALE)
VARIOUS OBSERVER POSITIONS (NOT TO SCALE)

Figure 9. Geometries for plume-based calculations for viewing of white, gray, and black objects for horizontal views perpendicular to the plume.

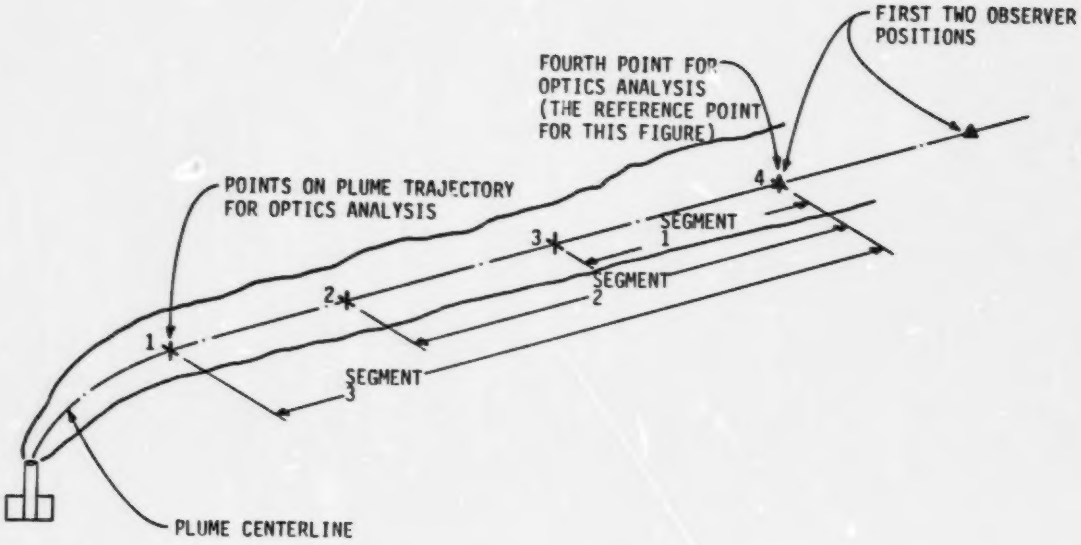

FIRST TWO OBSERVER POSITIONS
FOURTH POINT FOR OPTICS ANALYSIS (THE REFERENCE POINT FOR THIS FIGURE)
POINTS ON PLUME TRAJECTORY FOR OPTICS ANALYSIS
4
3
2
1
SEGMENT 1
SEGMENT 2
SEGMENT 3
PLUME CENTERLINE

Figure 10. Geometries for plume-based calculations for horizontal views along the axis of the plume.

particular point of analysis, as well as successive analysis points upwind. The calculations are repeated for observer positions at a range of distances from the downwind point at which the plume segment is assumed to end.

The observer-based geometry used for views through the plume center with a clear sky background is shown in figure 11. At each point of analysis along the plume trajectory, the optics calculation is made for only one scattering angle, one plume-observer distance, and one azimuthal angle specific for the source position, observer position, wind direction, date, and time of day used as input.

For calculations with white, gray, and black viewing backgrounds, the geometries are the same as those for horizontal views with a sky background (figure 12), with the addition of the specific background object distance, along each line of sight, from the observer through the points on the plume trajectory.

Figure 12 is a plan view of the geometry for an observer-based calculation for views along the plume. At each analysis point along the plume trajectory, the centerline concentration is integrated along a segment on the line of sight that would correspond to a Gaussian distribution. The line of sight is always horizontal. The calculation is performed for a clear sky background and for white, gray, and black viewing objects at the specific distance for each line of sight.

It should be noted that if the distance (r_p) and azimuthal angle (α) are such that the observer is within the plume, the total plume optical thickness along the line of sight is reduced accordingly. The calculated distance r_p is the distance between the observer and the centroid of plume material viewed by him.

QUANTIFYING VISIBILITY IMPAIRMENT

We can quantify visibility impairment once the spectral light intensity or radiance $I(\lambda)$ has been calculated for the specific lines of sight of an observer at a given location in an atmosphere with known aerosol and pollutant concentrations. Visibility impairment--including reduction in visual range, the perceptibility of plumes and haze layers, and atmospheric discoloration--is caused by changes in light intensity as a result of light scattering and absorption in the atmosphere.

The reader should refer to another volume in this regulatory guidance series entitled, "Quantifying Visibility Impairment," for further discussion of the parameters used by PLUVUE II to quantify visibility impairment.

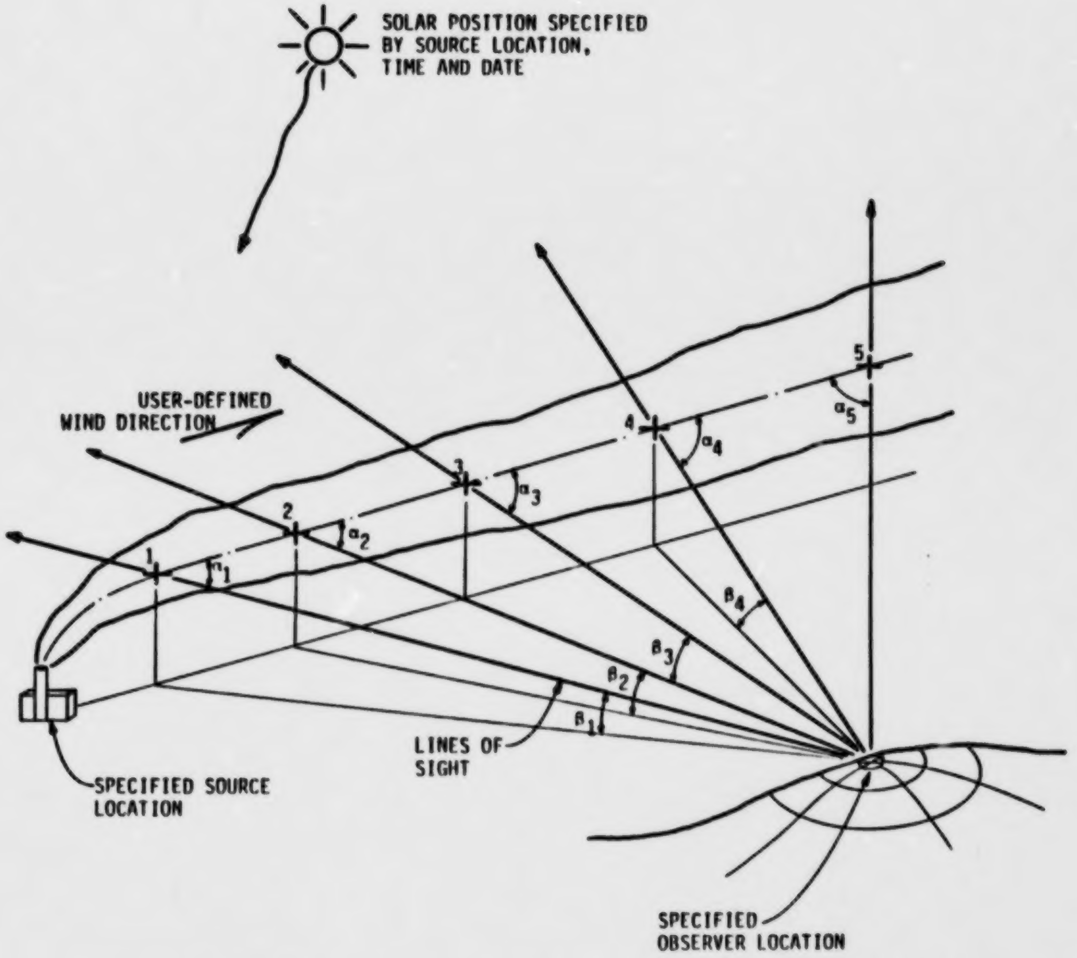

SOLAR POSITION SPECIFIED
BY SOURCE LOCATION,
TIME AND DATE
USER-DEFINED
WIND DIRECTION
1
2
3
4
5
α_1
α_2
α_3
α_4
α_5
β_1
β_2
β_3
β_4
LINES OF
SIGHT
SPECIFIED SOURCE
LOCATION
SPECIFIED
OBSERVER LOCATION

Figure 11. Geometry used for observer-based calculations for nonhorizontal views through the plume for clear-sky backgrounds.

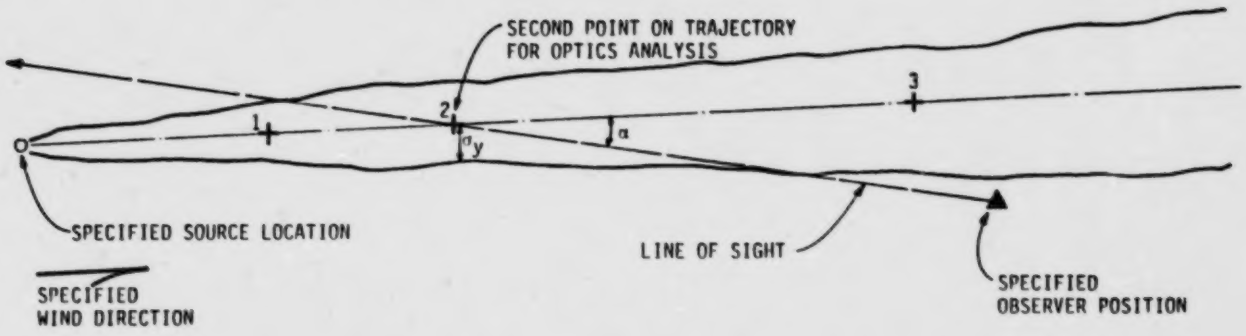

SECOND POINT ON TRAJECTORY
FOR OPTICS ANALYSIS
1
2
3
σ_y
α
SPECIFIED SOURCE LOCATION
SPECIFIED
WIND DIRECTION
LINE OF SIGHT
SPECIFIED
OBSERVER POSITION

Figure 12. Plan view of geometry for observer-based calculations for views along the plume.

SECTION 3

PLUVUE II INPUT DATA

The input data needed to run PLUVUE II are contained in one file of 80 byte, card-image records. These data include the following parameters:

- Wind speed aloft or at the 7-m level.
- Stability category.
- Lapse rate.
- Height of the planetary boundary layer (mixing depth).
- Relative humidity.
- SO_2, NO_x, and particulate emissions rates.
- Flue gas flow rate, exit velocity, and exit temperature.
- Flue gas oxygen content.
- Ambient air temperature at stack height.
- Ambient background NO_x, NO_2, O_3, and SO_2 concentrations.
- Properties (including density, mass median radius, and geometric standard deviation) of background and emitted aerosols in accumulation (0.1-1.0 μm), coarse (1.0-10.0 μm), and carbonaceous aerosol size modes.
- Coarse mode background aerosol concentration.
- Background visual range or background sulfate and nitrate concentration.
- Deposition velocities for SO_2, NO_x, coarse mode aerosol, and accumulation mode aerosol.
- UTM coordinates of the source location.
- Elevation of the source location.
- UTM coordinates and elevation of the observer location for an observer-based analysis.
- UTM zone for the site and observer locations.
- Time, day, month, year, and time zone for the time and date of the simulation.
- For an observer-based run, terrain elevation at the points along the plume trajectory at which the analysis will be performed.
- For an observer-based run with white, gray, and black viewing backgrounds, the distances from the observer to the terrain that will be observed behind the plume.
- For an observer-based run, the wind direction.

The input data file also has numerous switches or flags to allow the user to select the particular subset of the complete model that meets his needs. Table 1 lists the input parameters with formats, summary descriptions, and suggested values for some of the input parameters. The parameter IUSFC is simply a flag to allow the wind speed to be input at the effective stack height (IUSFC = 0) or at the common 7-m instrument height (IUSFC = 1).

IDIS is a flag that selects the desired Gaussian diffusion parameters, which may be Pasquill-Gifford (IDIS = 0), TVA (IDIS = 1), or user-input values (IDIS = 9).

IFLG1 is a flag that allows the user to select or skip the calculation of visibility impairment of the plume for horizontal views with a clear sky background. IFLG2 allows the user to select or skip the calculation of visibility impairment for nonhorizontal views and clear sky background. IFLG3 allows the user to select or skip the calculation of visibility impairment calculations of the plume as seen in front of white, gray, and black backgrounds. IFLG4 allows the user to select or skip the visibility impairment calculation for an observer looking straight down the centerline of various segments of the plume or for an observer looking across the plume at a small acute angle to the plume centerline. For all of these, a value of 1 executes the calculations and a value of 0 branches around them.

NZF is a switch that indicates whether the visibility impairment calculations will be made for the plume centerline altitude only (NZF = 1) or for both the plume centerline and ground level (NZF = 2).

IDILU is a switch that controls the printing of the table of initial plume rise data. If IDILU = 0, the table is not printed, and if IDILU =1, it is printed.

INTYP is a switch that allows the user to calculate the background visual range (INTYP = 1) from user-input background coarse mode aerosol concentrations and background sulfate and nitrate concentrations. If INTYP ≠ 1, the user inputs the background visual range and the background coarse mode aerosol concentration, and the model computes the background accumulation mode aerosol concentration that would be needed to cause the given visual range.

ICON is a switch that allows the user to select the conversion rate of SO_2 to $SO_4^=$, in addition to the rate calculated by the OH• model, as a constant with distance from the source (ICON = 0) or as a separate value for each point of analysis downwind from the source (ICON = 1). These

TABLE 1. DATA REQUIREMENTS FOR PLUVUE II

Card No.	Format	Variables	Description
1	6A4	PLANT	Name of source
2	F5.1	U	Wind speed (mph)
	I5	I	Stability index
	F5.2	ALAPSE	Ambient temperature lapse rate (°F/1000')
3	I2	IUSFC	Index for height for U (=1 for 7m, 0 for effective stack height)
	I2	INEW	Secondary stability index
	I2	NXSTAB	Index for downwind distance where stability changes from I to INEW
4	F10.0	YINITL	Initial plume y-dimension for area source
	F10.0	ZINITL	Initial plume z-dimension for area source
5	F10.1	HPBLM	Mixing depth (m)
6	F10.3	RH	Relative humidity (percent)
7	I5	IDIS	Flag indicating diffusion parameters to be used for stability index I ("1" for TVA, "0" for Pasquill-Gifford-Turner values, "9" for user input values
8	I2	IFLG1	Flag for optics calculation of horizontal views with sky background[*]
	I2	IFLG2	Flag for optics calculation with nonhorizontal views and sky background[*]
	I2	IFLG3	Flag for optics calculation for white, gray, and black background[*]

TABLE 1 (Continued)

Card No.	Format	Variable	Description
	I2	IFLG4	Flag for optics calculation along the plume centerline
	I2	NX2	Index indicating the number of downwind distances desired ($2 < NX2 < 16$)
	I2	NT1	Starting index for the scattering angles used in the generic calculation (set to 1 when executing only observer-based calculations)
	I2	NT2	Ending index for the scattering angles used in the plume-based calculation (set to 7 when executing only observer-based calculations)
	I2	NZF	Index for the number of altitudes for visual impact calculations: "1" for plume centerline only, "2" for plume centerline and ground-level downwind
9	I2	IDILU	Switch for printout of table for initial plume rise data
10	8F10.0	DIST(I) I=1, NX2	Downwind distances for visibility impact calculations ($2 < NX2 < 16$) (2 cards for $NX2 > 8$)
11	8F10.0	DIST(I)(cont.)	
12	F10.2	QSO2	Total SO_2 emissions rate from all stacks in tons per day
	F10.2	QNOX	Total NO_x emissions rate from all stacks in tons per day

TABLE 1 (Continued)

Card No.	Format	Variables	Description
	F10.2	QPART	Total primary particulate emissions rates from all stacks in tons per day
13	F10.1	FLOW	Flue gas flow rate (cfm) per stack
	F10.1	FGTEMP	Flue gas exit temperature (°F)
	F10.1	FGO2	Flue gas oxygen concentration (mole percent) [3]§
	F10.2	WMAX	Flue gas stack exit velocity (m/s)
14	F5.1	UNITS	Number of stacks
	F5.1	HSTACK	Stack height (feet)
15	F10.1	TAMB	Ambient temperature (°F)
16	F10.3	AMBNOX	Ambient [NO_x] in ppm [0]
	F10.3	AMBNO2	Ambient [NO_2] in ppm [0]
	F10.3	O3AMB	Ambient [O_3] in ppm [0.04]
	F10.3	AMBSO2	Ambient [SO_2] in ppm [0]
17	F10.3	ROVA	Mass median radius (μm) for background accumulation mode aerosol [0.16]
	F10.3	ROVC	Mass median radius (μm) for background coarse mode aerosol [3.0]
	F10.3	ROVS	Mass median radius (μm) for plume secondary aerosol [0.10]
	F10.3	ROVP	Mass median radius (μm) of emitted primary particulate [1.0]

TABLE 1 (Continued)

Card No.	Format	Variables	Description
18	F10.3	SIGA	Geometric standard deviation of background accumulation mode aerosol radius [2.0]
	F10.3	SIGC	Geometric standard deviation of background coarse mode aerosol radius [2.2]
	F10.3	SIGS	Geometric standard deviation of plume secondary aerosol radius [2.0]
	F10.3	SIGP	Geometric standard deviation of plume primary aerosol radius [2.0]
19	F10.3	DENA	Particle density (g/cm^3) of background accumulation mode aerosol [1.5]
	F10.3	DENC	Particle density (g/cm^3) of background coarse mode aerosol [2.5]
	F10.3	DENS	Particle density (g/cm^3) of plume secondary aerosol [1.5]
	F10.3	DENP	Particle density (g/cm^3) of emitted primary particulate [2.5]
20	F10.3	ROVCAR	Mass median radius (μm) for carbonaceous aerosol [0.05]
	F10.3	SIGCAR	Geometric standard deviation of carbonaceous aerosol radius [2.0]
	F10.3	DENCAR	Particle density (g/cm^3) of carbonaceous aerosol [2.0]
	F10.3	FRACTC	Carbonaceous aerosol fraction of plume primary aerosol [0.0]
	F10.3	AMBCAR	Background atmospheric carbonaceous aerosol (μg/m^3) [0.0]

TABLE 1 (Continued)

Card No.	Format	Variables	Description
21	F10.3	$RFRSO_4$	Real part of index of refraction for accumulation mode aerosol [1.5]
	F10.3	$RFISO_4$	Imaginary part of index of refraction for accumulation mode aerosol [0.0]
	F10.3	RFRCOR	Real part of index of refraction for background coarse mode aerosol [1.5]
	F10.3	RFICOR	Imaginary part of index of refraction for background coarse mode aerosol [0.0]
22	F10.3	RFRPRM	Real part of index of refraction for emitted primary aerosol [1.5]
	F10.3	RFIPRM	Imaginary part of index of refraction for emitted primary aerosol [0.0]
	F10.3	RFRCAR	Real part of index of refraction for carbonaceous aerosol [2.0]
	F10.3	RFICAR	Imaginary part of index of refraction for carbonaceous aerosol [1.0]
23	F10.3	CORAMB	Ambient coarse mode aerosol concentration ($\mu g/m^3$)
24	I5	INTYP	Switch for next card (=1 for $AMBSO_4$ and $AMBNO_3$, ≠ 1 for RVAMB)
25a (INTYP=1)	F10.3	AMBSO4	Ambient background sulfate mass concentration ($\mu g/m^3$)
	F10.3	AMBNO3	Ambient background nitrate mass concentration ($\mu g/m^3$)

TABLE 1 (Continued)

Card No.	Format	Variables	Description
25b (INTYP ≠ 1)	F10.3	RVAMB	Ambient background visual range (km)
26	F5.2	VDSO2	SO_2 deposition velocity (cm/sec) [1]
	F5.2	VDNOX	NO_x deposition velocity (cm/sec) [1]
	F5.2	VDCOR	Coarse mode aerosol deposition velocity (cm/sec) [0.1]
	F5.2	VDSUB	Accumulation mode aerosol deposition velocity (cm/sec) [0.1]
27	I5	ICON	Index for SO_2-to-$SO_4^=$ conversion rate added to rate predicted from OH• chemistry. ICON = 0 for conversion rate, set constant with distance from source. ICON = 1 for separate values for each point of analysis downwind of the source [0]
28	F10.7	RSO2C	Rate constant for SO_2-to-$SO_4^=$ conversion to be added to prediction from OH• chemistry (%/hr) [0.0]
A-1† (If ICON = 1)	8F10.7	RSO2(NX), NX=1,8	SO_2-to-$SO_4^=$ conversion rates to be added to predictions from OH• chemistry at each point of analysis on plume (%/hr)
A-2† (continuation of A-1)	8F10.7	RSO2(NX), NX=9,NX2	(Continuation as needed)
29	I5	NC1	Index to control type of calculations. NC1=1 for plume-based calculations, 2 for observer based calculations only

TABLE 1 (Continued)

Card No.	Format	Variable	Description
	I5	NC2	Index to control calculations NC2=1 for plume-based calculations only, 2 for observer-based calculations
A-3† (If NC1=1)	6I2	NPP	Indexes for controlling the subset of results (from plume-based calculations of horizontal views with sky, white, gray, and black backgrounds) to be written to a file for later use by the VISPLOT program for generating plots. NPP controls the distance from the observer to the plume for sky background [3]
		NAP	Index for selecting the horizontal azimuthal angle α between the line of sight and the plume trajectory for plots of results for sky backgrounds [4]
		NTP	Index for selecting the scattering angle of plume-based data to be plotted
		NZP	Index for selecting the level of the line of sight through the plume for plume-based data to be plotted [3]
		IO1P	Index for selecting the distance from the observer to the background object for the plume-based data to be plotted
		IPP	Index for selecting the distance from the observer to the plume for plume-based plot data with background object views

TABLE 1 (Continued)

Card No.	Format	Variables	Description
A-3† (If NC2=2)	F10.1	XOBS	UTM x-coordinate of observer position (in km) for observer-based calculations
	F10.1	YOBS	UTM y-coordinate of observer position (km)
	F10.1	ZOBS	Elevation (feet msl) of observer position
30	F10.1	XSTACK	UTM x-coordinate of source (km)
	F10.1	YSTACK	UTM y-coordinate of source (km)
	F10.1	ZSTACK	Elevation of source location (ft. MSL)
31	I5	IZONE	UTM grid zone number within which source is located
	I5	IMO	Number of month for date of simulation
	I5	IDAY	Day of month for date of simulation
	F5.0	TIME	Time of day (24-hr clock)
	F5.0	TZONE	Time zone number
	I5	IYEAR	Year for date of simulation
A-4† (If NC2=2)	8F10.1	TER(NX), NX=1,8	Elevation of terrain at the selected points downwind of the source along the plume trajectory (ft. MSL) (for observer-based calculation)
A-5† (If NC2=2)	8F10.1	TER (NX), NX=9, NX2	(Continuation as needed)
A-6† (If NC2=2)	8F10.1	ROBJCT(NAZ), NAZ=1,8	Distances in kilometers from observer to background terrain for observer azimuths of 15°, 30°, 45°, 60°, 75°, 90°, 105°, 120°

TABLE 1 (Concluded)

Card No.	Format	Variable	Description
A-7[†] (continuation of A-4)	8F10.1	ROBJCT(NAZ), NAZ=9,16	Distances for azimuths of 135°, 150°, 165°, 180°, 195°, 210°, 225°, 240°
A-8[†] (continuation of A-5)	8F10.1	ROBJCT(NAZ), NAZ=17,24	Distances for azimuths of 255°, 270°, 285°, 300°, 315°, 330°, 345°, 360°
A-9[†] (If NC2=2)	F10.1	WIND	Wind direction azimuth (degrees from North)
A-10[†] (If IDIS=9)	F5.1	SY	Dispersion parameters in meters,
(to A-10[†] + NX2)	F5.1	SZ	one card for each distance

---

[*] "0" if table is not desired, "1" if desired.

[†] "A-n" refers to cards that are optional. They are inserted only when values of prior flags or indexes are set to require additional input data, e.g., when ICON=1, cards A-1 and A-2 are required.

[§] Suggested values for some of the input parameters are shown in brackets.

conversion rates are in units of percent per hour. RSO2C gives the constant conversion rate for all points on the plume trajectory, while RSO2 gives the downwind-distance-dependent conversion rates for each point of analysis.

The parameters NC1 and NC2 are used to control whether the visibility impairment calculations are done for a plume-based scheme, an observer-based scheme, or both. NC1 set to 1 executes the plume-based calculations and NC2 set to 2 calculates the observer-based calculations. If NC1 is set to 1 and NC2 is set to 2, both types of calculations will be made. If NC1 is set to 1 and NC2 is set to 1, only the plume-based calculations will be made. Finally, if NC1 is set to 2 and NC2 is set to 2, only the observer-based calculations will be made.

The stability index I specifies the stability category for the plume dispersion parameters: I = 1 for stability A, I = 2 for stability B, I = 3 for stability C, etc. INEW and NXSTAB allow for a stability change at some point downwind along the plume trajectory. INEW is the new stability and NXSTAB is the index of the element of downwind distance array where the stability changes. If no stability change is desired, simply set INEW to I and NXSTAB to the value of NX2 plus one.

NT1 and NT2 assign the starting and ending indexes for the scattering angle array used for the plume-based visibility impairment calculations. With NT1 = 1 and NT2 = 7, the default scattering angles (22°, 45°, 90°, 135°, 158°, and 180°) are used. These angles are taken from the array TT, which has 0°, 22°, 45°, 90°, 135°, 158°, and 180° as its first seven elements. NT1 is one less than the actual starting index of TT, while NT2 corresponds to the actual ending index of TT. For a run with calculations for 90° only, NT1 is set to 3 and NT2 is set to 4. For a run with calculations for 90°, 135°, 158°, and 180°, NT1 is set to 3 and NT2 is set to 7.

The index NX2 defines the number of points downwind along the plume trajectory where visibility impairment calculations will be made. The value of NX2 should be at least, but not greater than, 16.

The array DIST specifies the distance downwind from the source along the plume trajectory of each point where visibility impairment calculations will be made. The units for this array are kilometers. For accurate prediction of the oxidation of NO_x to NO_2, it is important to use downwind distances that are close together and near the source. The first downwind distance must be 1 km; 2.5 km, 5 km, and 10 km are recommended for the succeeding three distances. The user is free to select the remaining points according to the needs of the situation.

YINITL and ZINITL are used for area sources and define the initial lateral and vertical dimensions of the plume. For emissions from stacks, both YINITL and ZINITL should be set to zero. The units for these two variables are meters.

When plume-based calculations are complete, a subset of the results must be selected for plotting with the program VISPLOT (Appendix C). VISPLOT is designed to plot the visibility impairment parameters from the calculations for horizontal views with a sky background and for horizontal views with white, gray, and black object backgrounds. The six indexes listed on card A-3 determine the subset of results that will be written to logical file unit eight. NPP selects the distance from the observer to the plume in the following manner:

NPP	Distance from Observer to Plume (fraction of background visual range)
1	0.02
2	0.05
3	0.10
4	0.20
5	0.50
6	0.80

NAP determines the horizontal azimuthal angle alpha between the plume centerline and the line of sight for a sky background:

NAP	Alpha (degrees)
1	30°
2	45°
3	60°
4	90°

NTP selects the scattering angle between the direct solar beam and the line of sight from the point of analysis to the observer. The value of NTP must be greater than or equal to NT1 and less than or equal to (NT2-1). The values of NTP for each of the six scattering angles are shown below:

NTP	Scattering Angle (degrees)
1	22°
2	45°
3	90°
4	135°
5	158°
6	180°

NZP selects the results for calculations of views through the center of the plume or views at ground level across the plume trajectory. The values of NZP are limited by the value of NZF (card no. 8). If NZF = 1, the calculations are done only for views through the plume centerline, and NZP must be set to 3. If NZF = 2, NZP may be set to 3 for values from calculations for views through the plume centerline, or NZP may be set to 6 for values from calculations for views at the surface through the plume trajectory. The index IPP selects the distance from the observer to the plume for plotting results of the calculations for views with white, gray, and black objects behind the plume. The values of IPP correspond to the distances shown below:

IPP	Distance from Observer to Plume (fraction of background visual range)
1	0.02
2	0.05
3	0.10
4	0.20
5	0.50
6	0.80

I01P is used to select the distance from the observer through the plume to the white, gray, and black background objects behind the plume. The value of I01P is limited by the value of IPP because the object background can be no farther than a distance equivalent to 80 percent of the background visual range from the observer. If IPP = 1, the range of values of I01P is shown below:

I01P	Distance from Observer to Object (fraction of background visual range)
1	0.02
2	0.05
3	0.10
4	0.20
5	0.50
6	0.80

When IPP = 2, the values I01P available are as follows:

I01P	Distance from Observer to Object
1	0.05
2	0.10
3	0.20
4	0.50
5	0.80

When IPP = 3, I01P is limited to one of the following values:

I01P	Distance
1	0.10
2	0.20
3	0.50
4	0.80

When IPP = 4, I01P is limited to these three values:

I01P	Distance
1	0.20
2	0.50
3	0.80

When IPP = 5, I01P is limited to only two values:

I01P	Distance
1	0.50
2	0.80

When IPP = 6, I01P must be set to 1, which corresponds to a distance from the observer to the background object of 0.80 of the background visual range. These six indexes do not place any restrictions on the calculations made by PLUVUE II, but they provide a means of selecting the desired subset of results to be saved for plotting.

The UTM coordinates and elevations for observer and source locations and the UTM grid zone numbers are taken from standard USGS maps. TZONE is the number of the time zone, with the Greenwich Meridian defined as 0. Values of TZONE are shown below:

Time Zone	Standard Time	Daylight Time
Eastern	5	4
Central	6	5
Mountain	7	6
Pacific	8	7

The array TER gives the elevation of terrain at each point downwind for the visibility analysis. For the purpose of calculating plume-observer-sun geometry only, the plume centerline is assumed to rise above any terrain higher than the source elevation in order to maintain the same effective height above the terrain for all points downwind. If the terrain is flat or if it is desirable to maintain the same plume elevation at all points, use zero for all TER values. The model will then set all terrain elevations to the elevation of the source location.

The ROBJT array allows the user to define the distances from the observer to the background terrain. These distances are read in for observer azimuths of from 15° to 360° in 15° increments. The distances are measured in kilometers by creating a terrain profile for each azimuth and determining the point at which the line of sight intersects the terrain. The observer-based calculations can be performed without measuring these values by setting all elements of the ROBJT array to zero. The background object distance will then be set to the observer-to-plume distance for each line of sight. WIND is the direction from which the wind is blowing, expressed in degrees.

For user-defined values of plume dispersion parameters (IDIS = 9), SY and SZ are read for each downwind distance. SY is the plume concentration horizontal standard deviation and SZ is the plume concentration vertical standard deviation in meters.

SECTION 4

PLUVUE II OUTPUT

Examples of the various types of outputs that can be obtained with PLUVUE and PLUVUE II have been presented by Johnson et al. (1980), and the reader is referred to that document for detailed information on the output generated by PLUVUE II.

A typical output of PLUVUE II for an observer-based simulation is presented in Appendix A. A typical output of PLUVUE II for a plume-based simulation is presented in Appendix B.

A PLUVUE run will write results on three files: the print file on logical file unit six, the observer-based perceptibility data for plotting on logical file unit seven, and the plume-based plot data on logical file unit eight. If a PLUVUE run is for either observer-based or plume-based calculations, either an observer-based or a plume-based plot file will be created. The principal PLUVUE run output is the print file written on logical unit six. The file size depends on the number and type of calculations invoked by the input file. All runs contain data tables for the emission source, meteorological and ambient air quality, and background radiative transfer.

SECTION 5

PLUVUE II PROCEDURE FLOW CHART

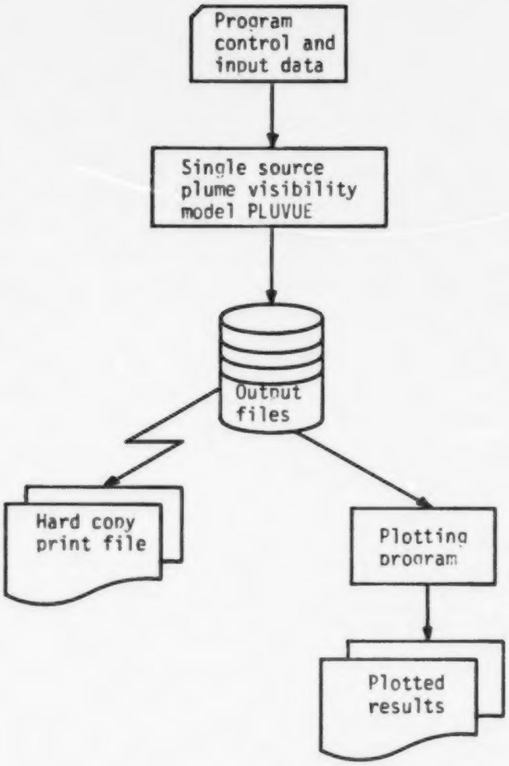
OVERVIEW OF THE FLOW CHART

The procedure flow of PLUVUE II is represented in the following figures. Figure 13a depicts the relationship of input and output to a PLUVUE II model execution. Figure 13b illustrates the general procedure flow of PLUVUE II. This diagram provides the user with a guide to the general organization of the model. Figure 13c is a more detailed flow diagram of MAIN. Figures 13d through 13m provide flow diagrams of the subroutines INRAD, BSIZE, BACCLI, RAYREI, PERDIF, BACCLN, BACOBJ, PLMCLN, PLMOBJ, AND PLMAX, respectively. These diagrams represent the flow of the program execution in these routines without attempting to represent individual lines. Other PLUVUE II subroutines are so short that procedure flow diagrams are not useful at the level of detail presented.

CHANGES IN THE COMPUTER CODE FROM PLUVUE TO PLUVUE II

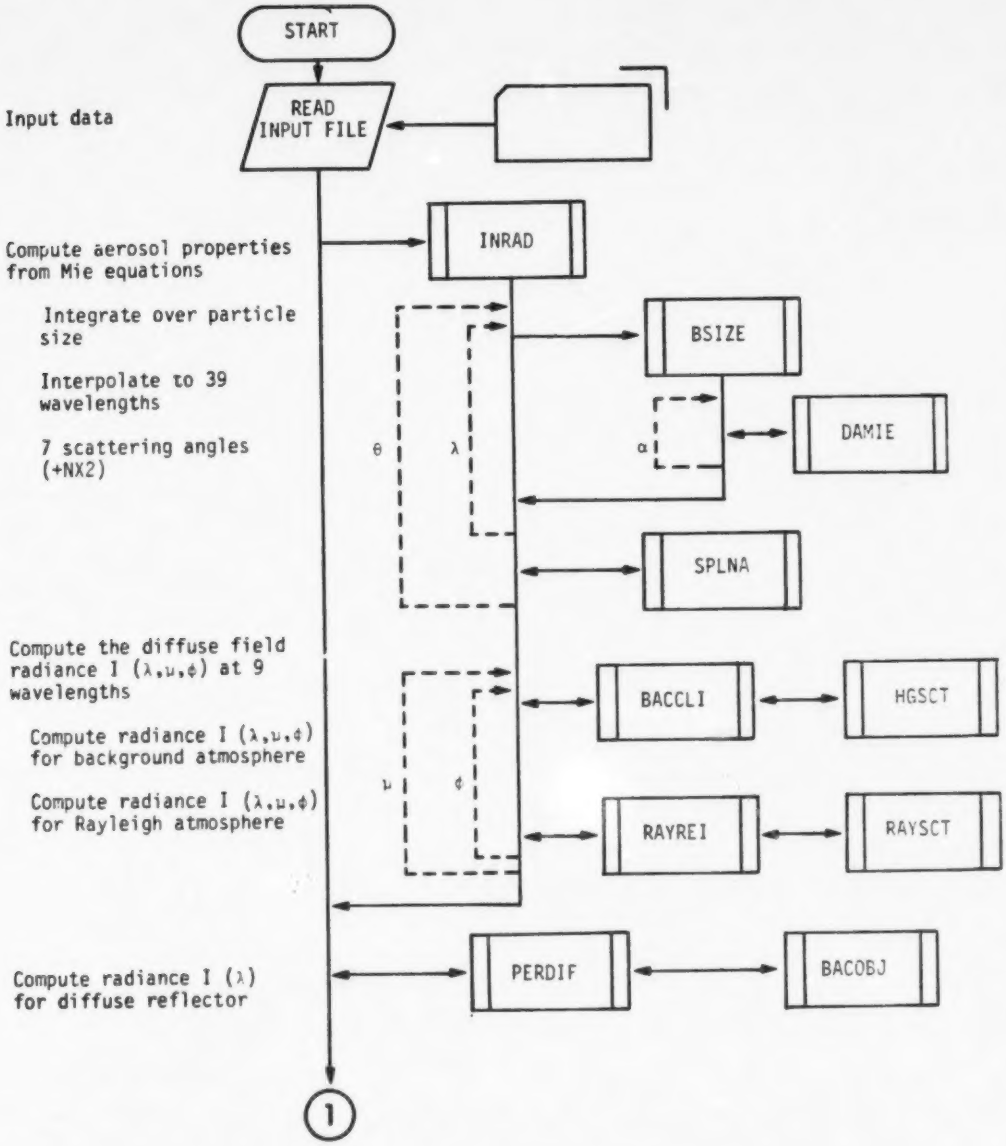
Several changes have been made to the PLUVUE computer code to implement an improved treatment of atmospheric optics. These changes, which include light absorption by carbonaceous aerosols and the anisotropic modeling of multiple-scattering radiation, are summarized in the ensuing paragraphs.

Modifications to the subroutine BSIZE have been made to provide a more flexible approach to the calculation of the aerosol optical properties. The basic calculations of the extinction, scattering, and absorption parameters are now carried out with the subroutine DAMIE for some specific points in the α-space, where α is defined as r/λ, with r = aerosol radius and λ = radiation wavelength. The values of the aerosol optical properties for other values of α are calculated by interpolating between the values of α provided by the subroutine DAMIE. The interpolation is performed by means of a second-order polynomial. This approach allows for substantial savings in computational time.


Program control and input data
Single source plume visibility model PLUVUE
Output files
Hard copy print file
Plotting program
Plotted results

(a) Relation of I/O to PLUVUE II.

Figure 13. PLUVUE logic flow chart.


START
Input data
READ INPUT FILE
Compute aerosol properties from Mie equations
INRAD
Integrate over particle size
BSIZE
Interpolate to 39 wavelengths
7 scattering angles (+NX2)
θ
λ
α
DAMIE
SPLNA
Compute the diffuse field radiance I (λ,μ,ϕ) at 9 wavelengths
BACCLI
HGSCT
Compute radiance I (λ,μ,ϕ) for background atmosphere
Compute radiance I (λ,μ,ϕ) for Rayleigh atmosphere
μ
ϕ
RAYREI
RAYSCT
Compute radiance I (λ) for diffuse reflector
PERDIF
BACOBJ
1

(b) Overview of the PLUVUE II structure.

Figure 13 (continued)

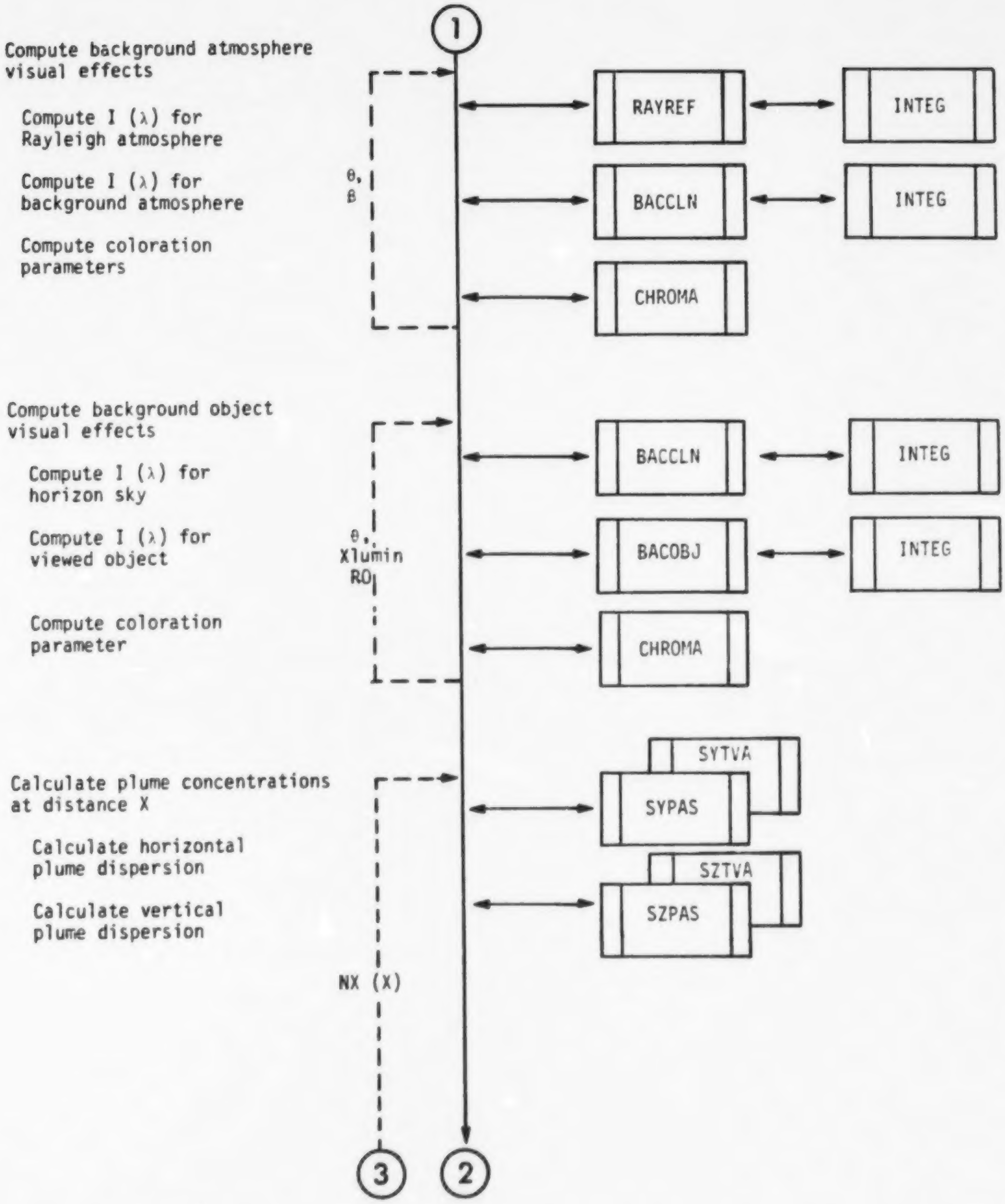

1
Compute background atmosphere visual effects
Compute I (λ) for Rayleigh atmosphere
Compute I (λ) for background atmosphere
Compute coloration parameters
θ, β
RAYREF
INTEG
BACCLN
INTEG
CHROMA
Compute background object visual effects
Compute I (λ) for horizon sky
Compute I (λ) for viewed object
Compute coloration parameter
θ, Xlumin RO
BACCLN
INTEG
BACOBJ
INTEG
CHROMA
Calculate plume concentrations at distance X
Calculate horizontal plume dispersion
Calculate vertical plume dispersion
SYTVA
SYPAS
SZTVA
SZPAS
NX (X)
3
2

Figure 13b (continued)

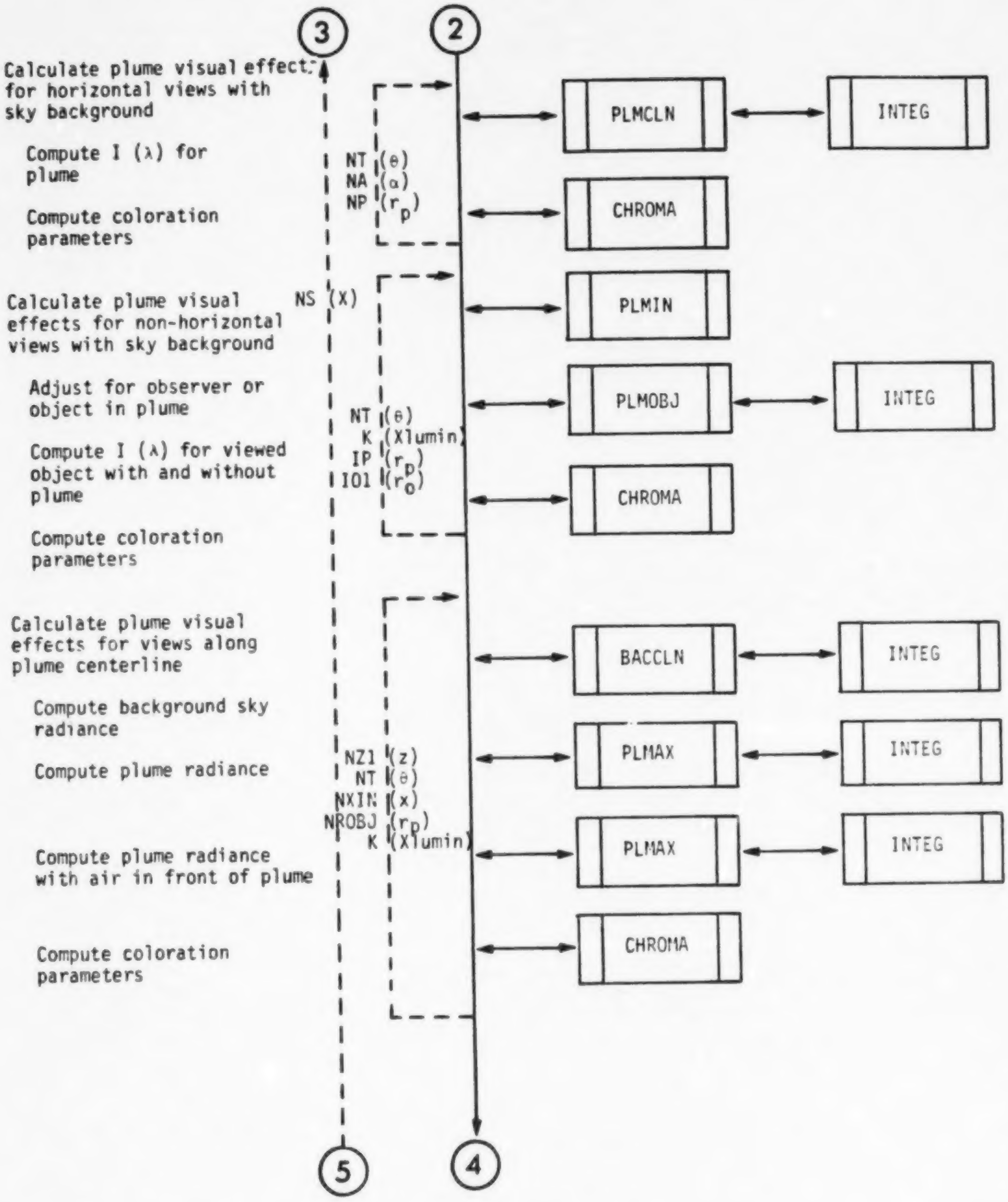

3
2
Calculate plume visual effects for horizontal views with sky background
Compute I (λ) for plume
Compute coloration parameters
NT (θ)
NA (α)
NP (r_p)
PLMCLN
INTEG
CHROMA
Calculate plume visual effects for non-horizontal views with sky background
NS (X)
Adjust for observer or object in plume
Compute I (λ) for viewed object with and without plume
Compute coloration parameters
NT (θ)
K (Xlumin)
IP (r_p)
IO1 (r_o)
PLMIN
PLMOBJ
INTEG
CHROMA
Calculate plume visual effects for views along plume centerline
Compute background sky radiance
Compute plume radiance
Compute plume radiance with air in front of plume
Compute coloration parameters
NZ1 (z)
NT (θ)
NXIN (x)
NROBJ (r_p)
K (Xlumin)
BACCLN
INTEG
PLMAX
INTEG
PLMAX
INTEG
CHROMA
5
4

Figure 13b (continued)

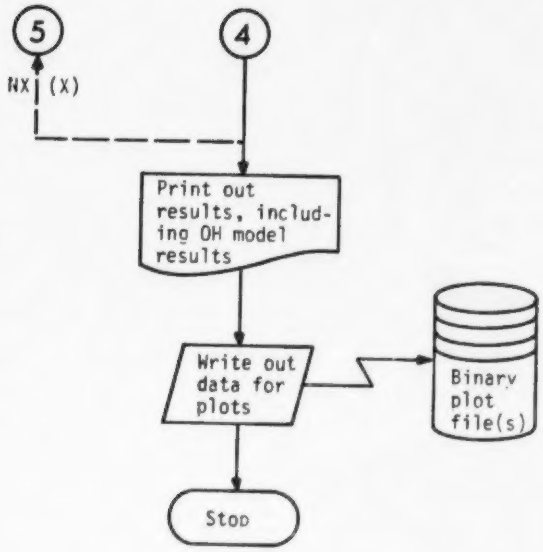
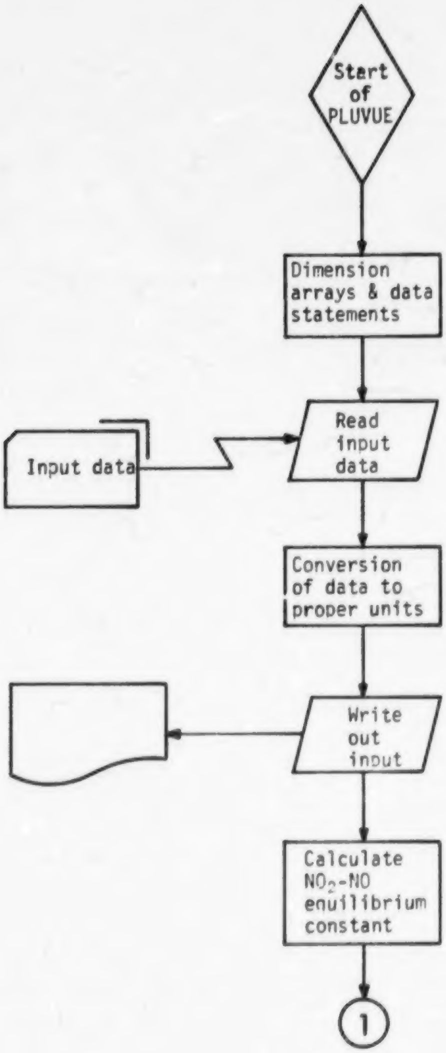

5
4
NX
(X)
Print out results, including OH model results
Write out data for plots
Binary plot file(s)
Stop

Figure 13b (concluded)


Start of PLUVUE
Dimension arrays & data statements
Input data
Read input data
Conversion of data to proper units
Write out input
Calculate NO_2-NO equilibrium constant
1

(c) Flow chart of MAIN.

Figure 13 (continued)

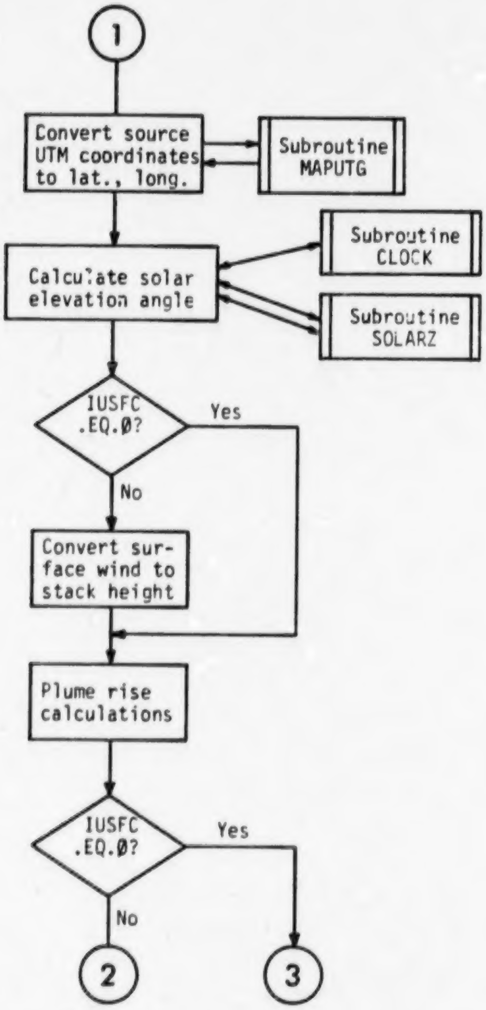

1
Convert source UTM coordinates to lat., long.
Subroutine MAPUTG
Calculate solar elevation angle
Subroutine CLOCK
Subroutine SOLARZ
IUSFC .EQ.0?
Yes
No
Convert surface wind to stack height
Plume rise calculations
IUSFC .EQ.0?
Yes
No
2
3

Figure 13c (continued)

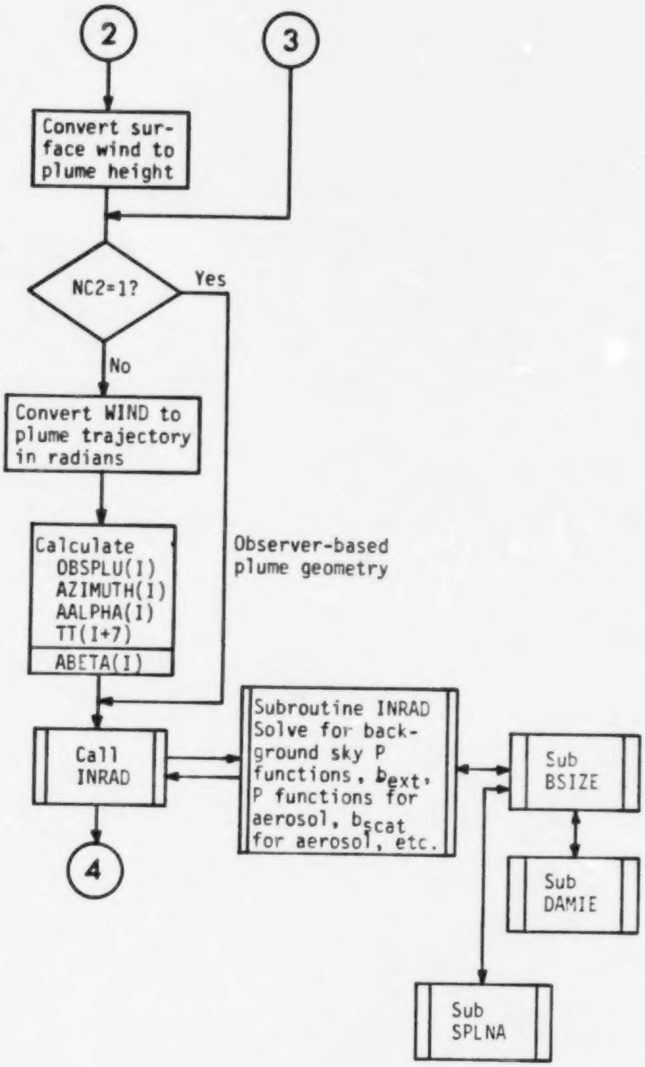

2
3
Convert surface wind to plume height
NC2=1?
Yes
No
Convert WIND to plume trajectory in radians
Calculate
OBSPLU(I)
AZIMUTH(I)
AALPHA(I)
TT(I+7)
ABETA(I)
Observer-based plume geometry
Call INRAD
Subroutine INRAD Solve for background sky P functions, b_ext, P functions for aerosol, b_scat for aerosol, etc.
Sub BSIZE
Sub DAMIE
Sub SPLNA
4

Figure 13c (continued)

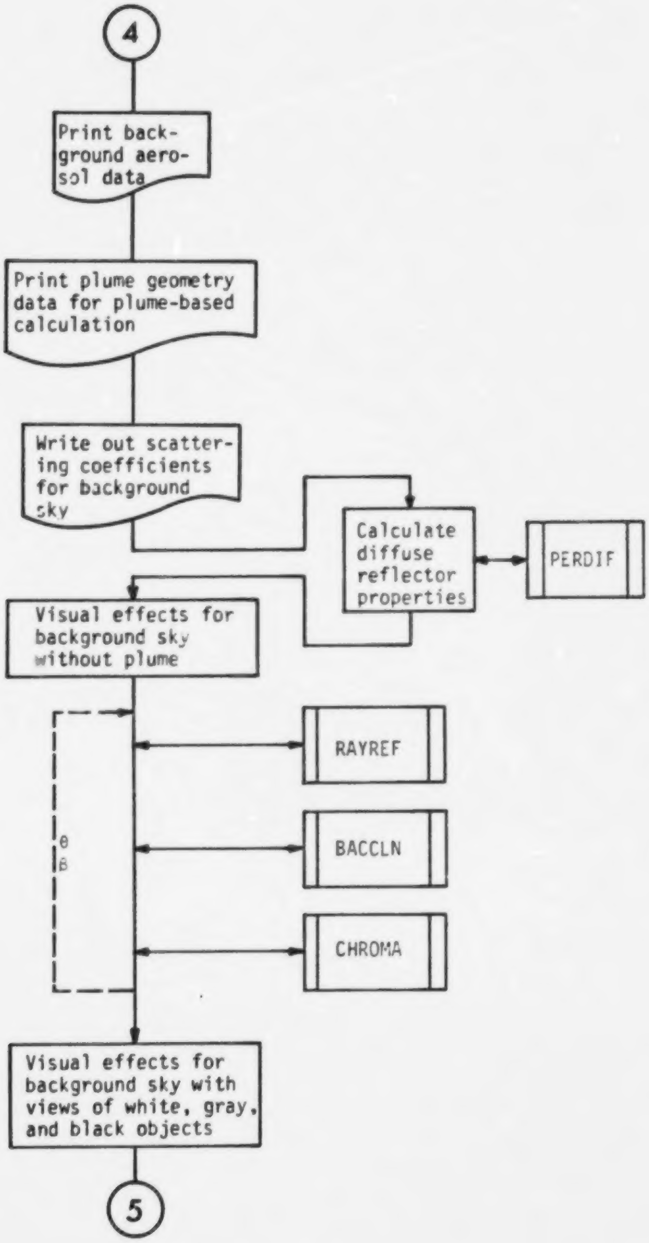
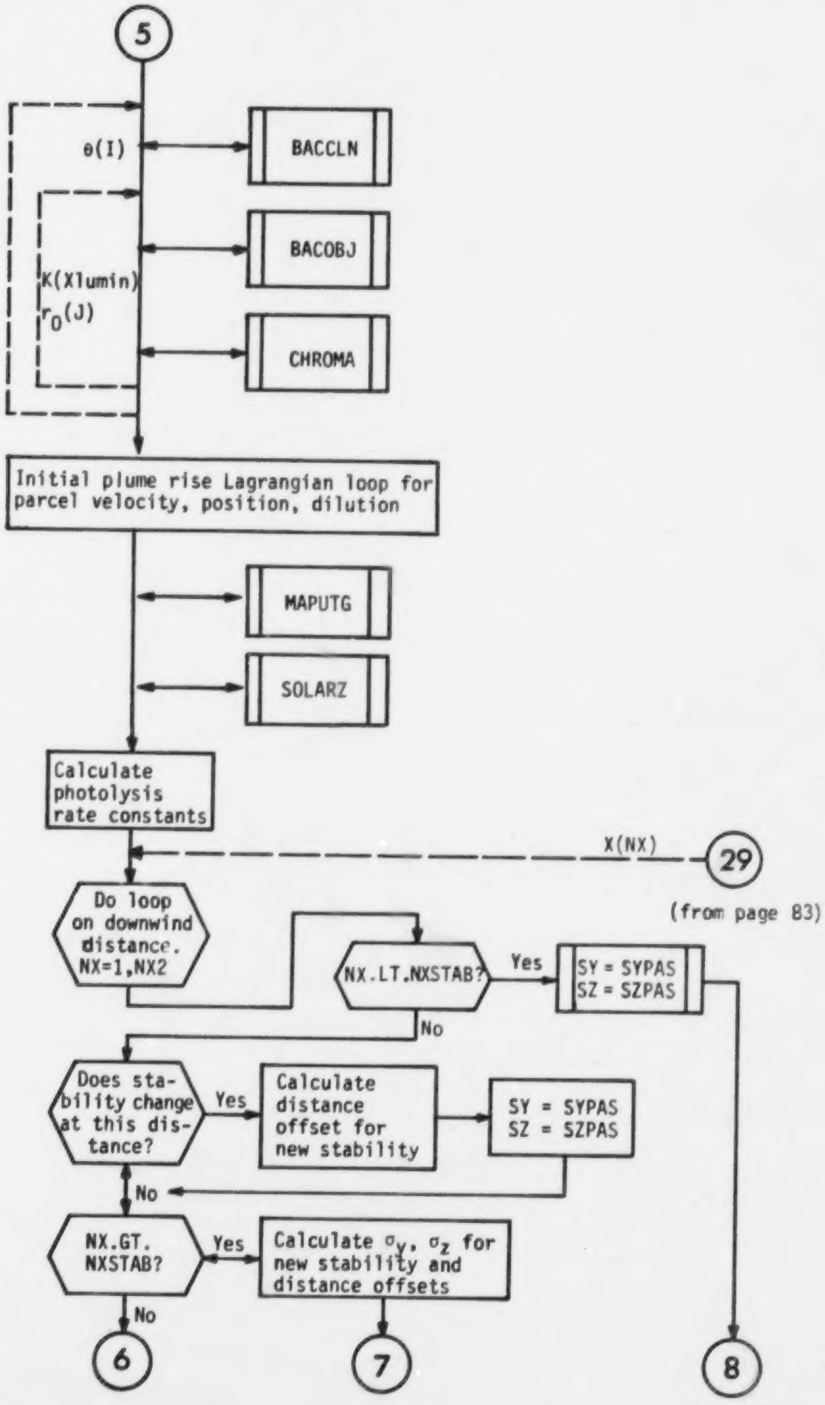

4
Print background aerosol data
Print plume geometry data for plume-based calculation
Write out scattering coefficients for background sky
Calculate diffuse reflector properties
PERDIF
Visual effects for background sky without plume
RAYREF
θ
B
BACCLN
CHROMA
Visual effects for background sky with views of white, gray, and black objects
5

Figure 13c (continued)



5
θ(I)
BACCLN
BACOBJ
K(Xlumin)
r_0(J)
CHROMA
Initial plume rise Lagrangian loop for parcel velocity, position, dilution
MAPUTG
SOLARZ
Calculate photolysis rate constants
X(NX)
29
(from page 83)
Do loop on downwind distance. NX=1,NX2
NX.LT.NXSTAB?
Yes
SY = SYPAS
SZ = SZPAS
No
Does stability change at this distance?
Yes
Calculate distance offset for new stability
SY = SYPAS
SZ = SZPAS
No
NX.GT. NXSTAB?
Yes
Calculate σ_y, σ_z for new stability and distance offsets
No
6
7
8

Figure 13c (continued)

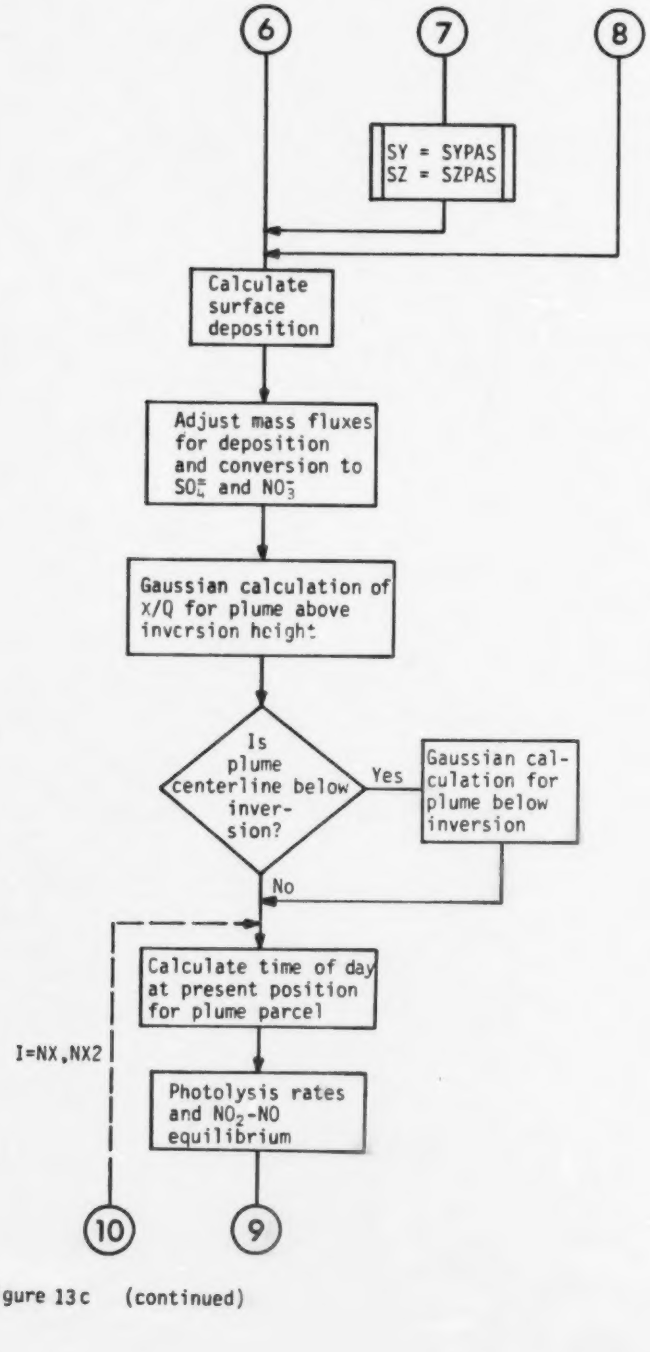

6
7
8
SY = SYPAS
SZ = SZPAS
Calculate surface deposition
Adjust mass fluxes for deposition and conversion to $SO_4^=$ and NO_3^-
Gaussian calculation of X/Q for plume above inversion height
Is plume centerline below inversion?
Yes
Gaussian calculation for plume below inversion
No
Calculate time of day at present position for plume parcel
I=NX,NX2
Photolysis rates and NO_2-NO equilibrium
10
9

Figure 13c (continued)

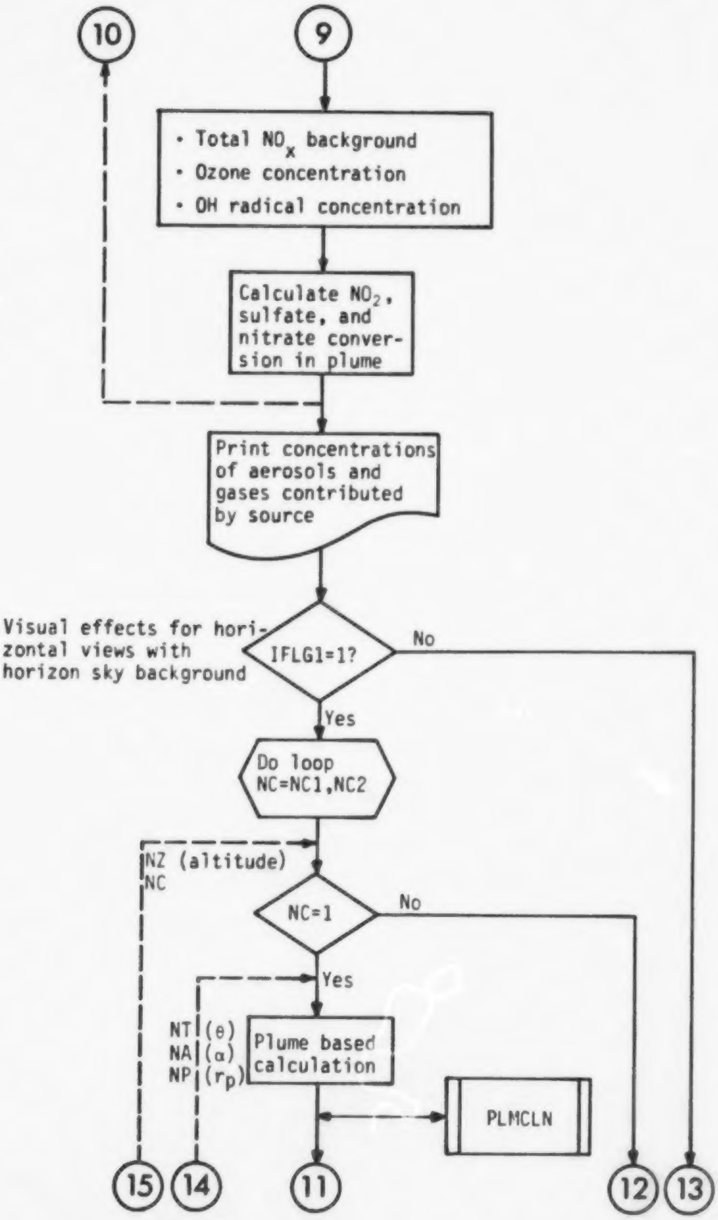

10
9
• Total NO_x background
• Ozone concentration
• OH radical concentration
Calculate NO_2, sulfate, and nitrate conversion in plume
Print concentrations of aerosols and gases contributed by source
Visual effects for horizontal views with horizon sky background
IFLG1=1?
No
Yes
Do loop NC=NC1,NC2
NZ (altitude)
NC
NC=1
No
Yes
NT (θ)
NA (α)
NP (r_p)
Plume based calculation
PLMCLN
15
14
11
12
13

Figure 13c (continued)

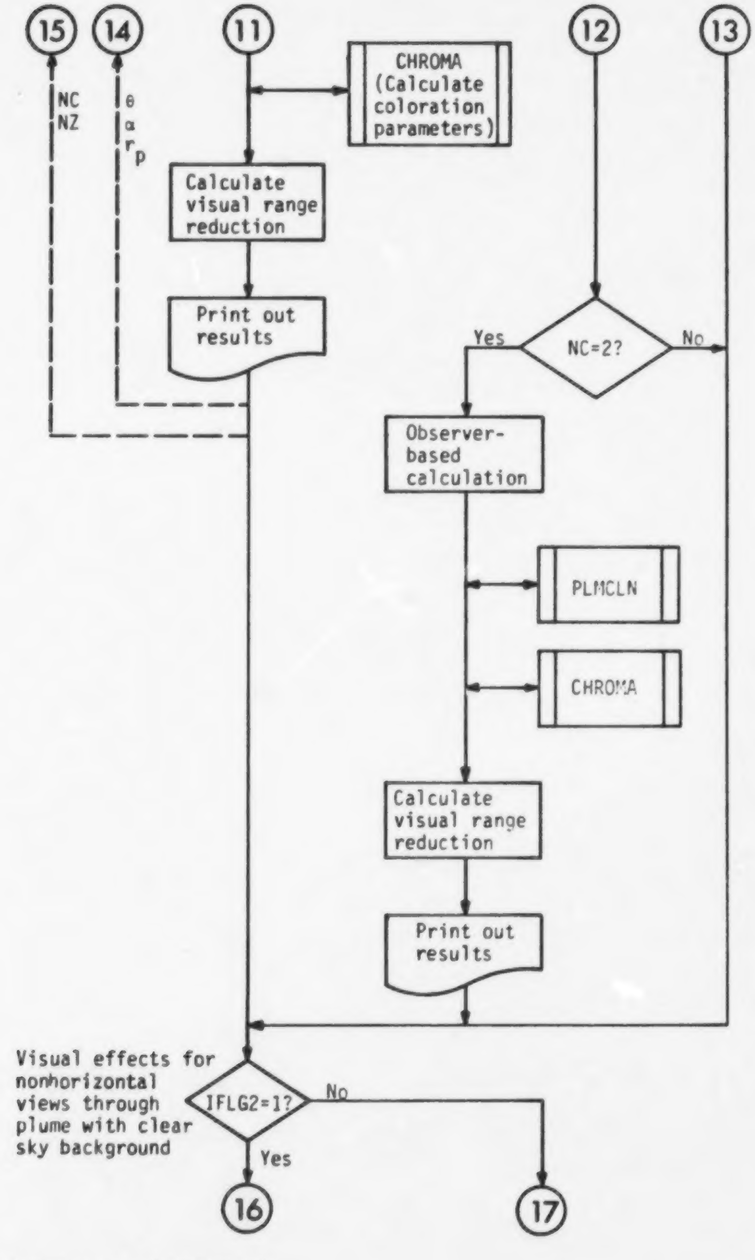

15
14
11
12
13
NC
NZ
θ
α
r_p
CHROMA (Calculate coloration parameters)
Calculate visual range reduction
Print out results
NC=2?
Yes
No
Observer-based calculation
PLMCLN
CHROMA
Calculate visual range reduction
Print out results
Visual effects for nonhorizontal views through plume with clear sky background
IFLG2=1?
No
Yes
16
17

Figure 13c (continued)

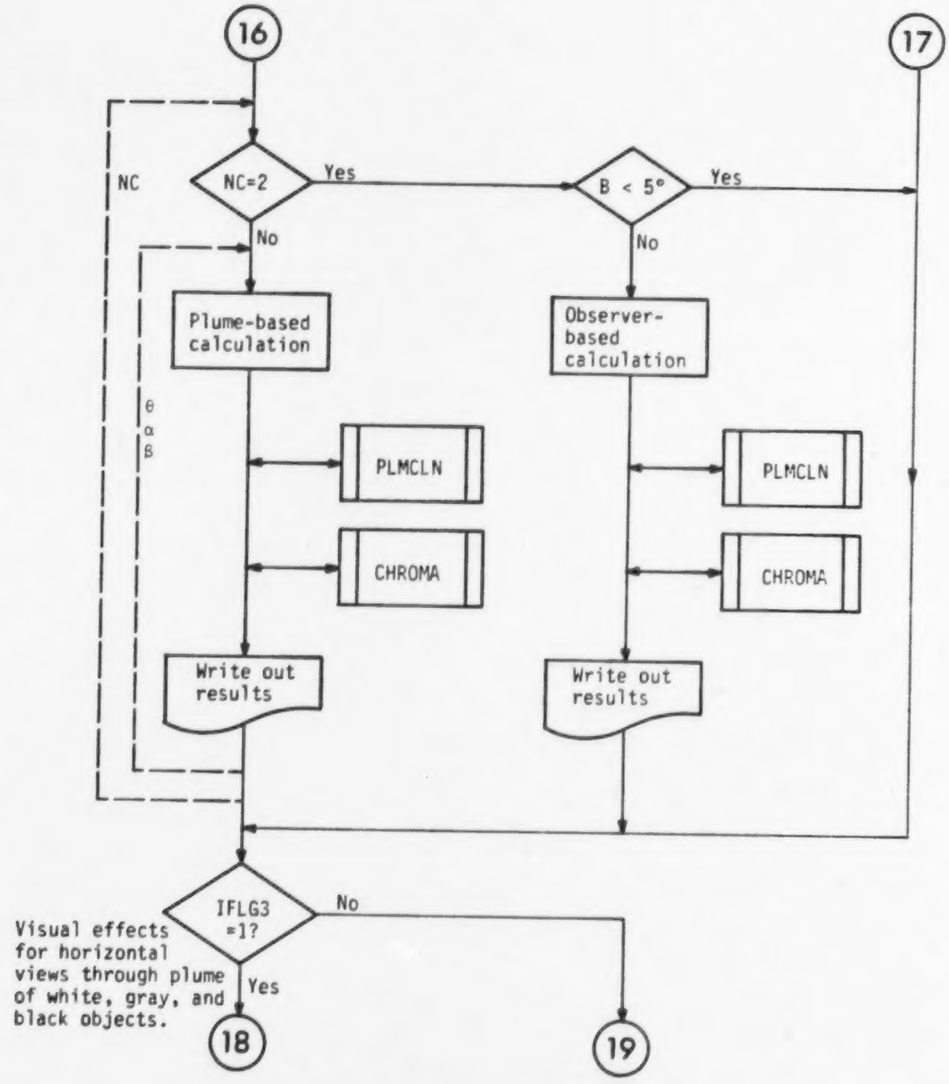

16
17
NC=2
Yes
B < 5°
Yes
NC
No
No
Plume-based calculation
Observer-based calculation
θ
α
β
PLMCLN
PLMCLN
CHROMA
CHROMA
Write out results
Write out results
IFLG3 =1?
No
Visual effects for horizontal views through plume of white, gray, and black objects.
Yes
18
19

Figure 13c (continued)

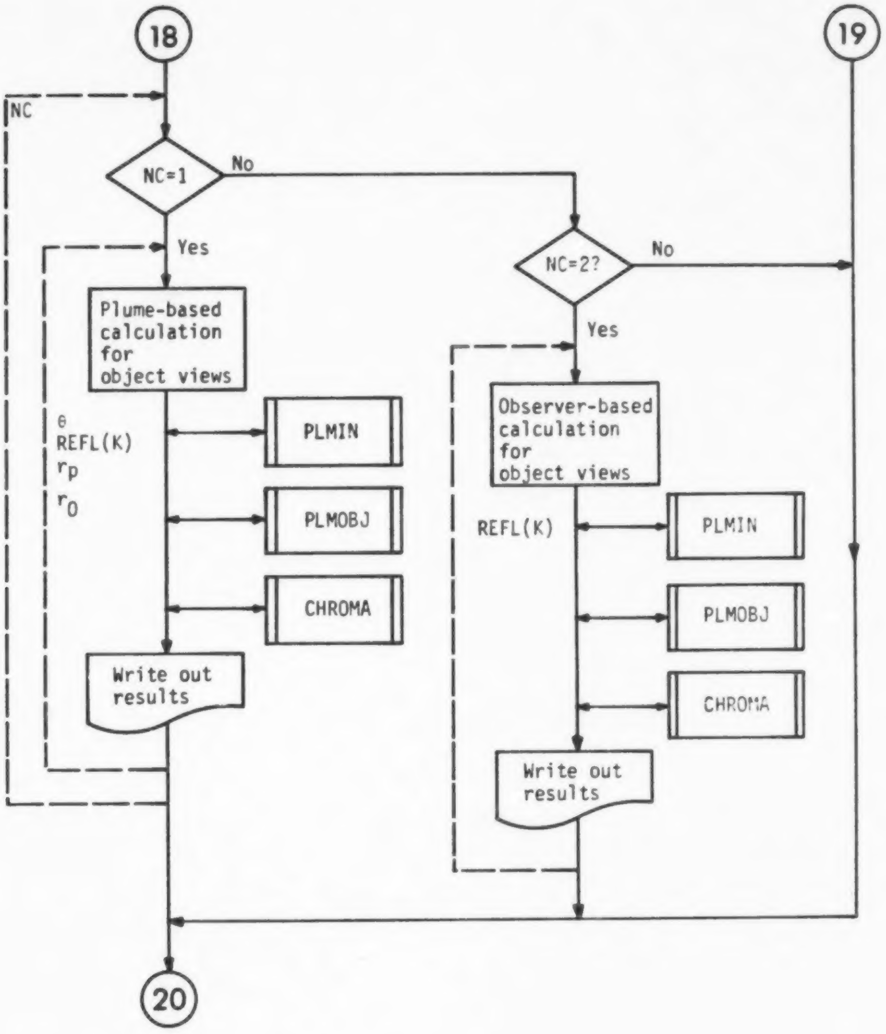

18
19
NC
NC=1
No
Yes
NC=2?
No
Yes
Plume-based calculation for object views
θ
REFL(K)
r_p
r_o
PLMIN
PLMOBJ
CHROMA
Write out results
Observer-based calculation for object views
REFL(K)
PLMIN
PLMOBJ
CHROMA
Write out results
20

Figure 13c (continued)

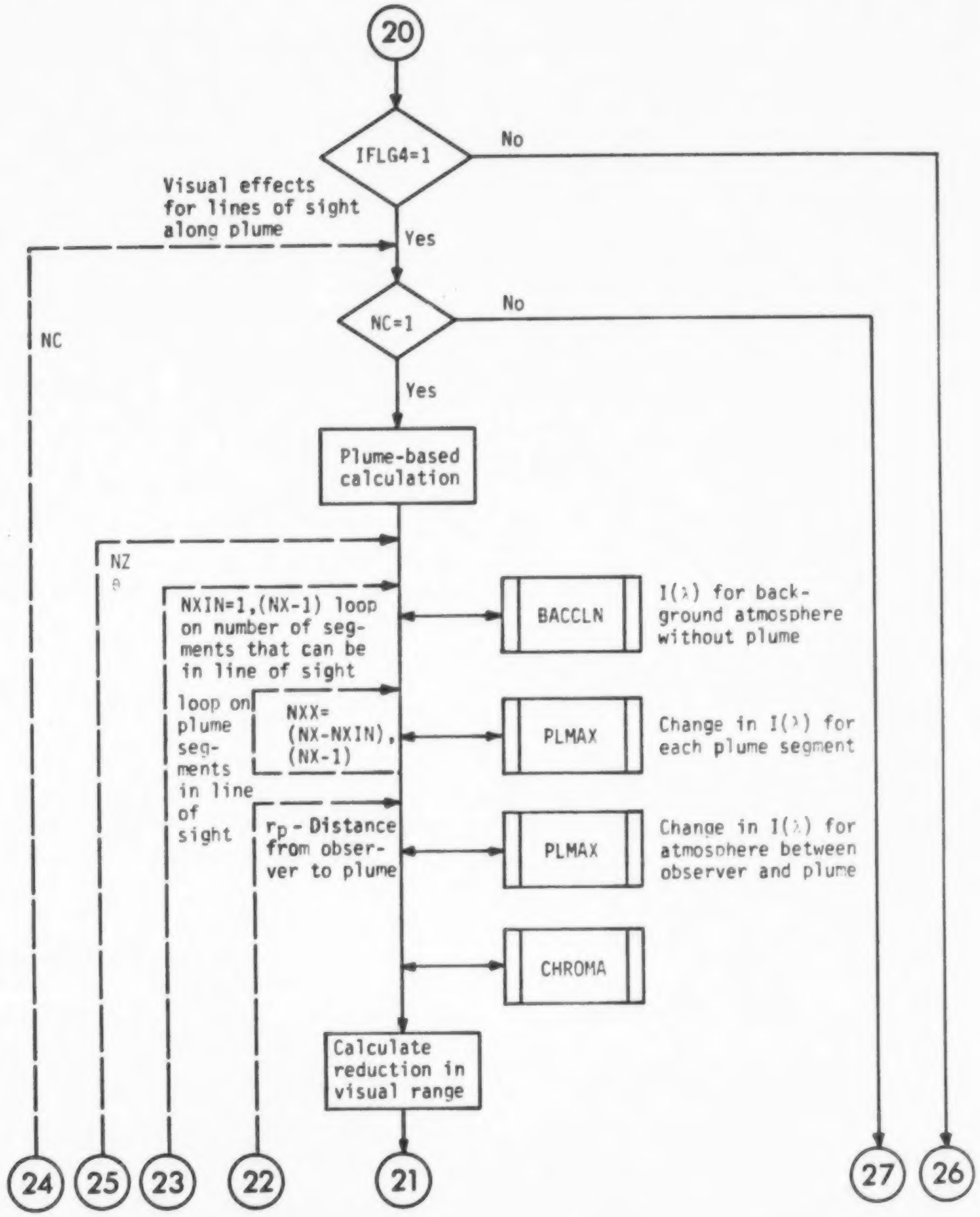

20
IFLG4=1
No
Visual effects
for lines of sight
along plume
Yes
NC=1
No
NC
Yes
Plume-based
calculation
NZ
θ
NXIN=1,(NX-1) loop
on number of seg-
ments that can be
in line of sight
BACCLN
I(λ) for back-
ground atmosphere
without plume
loop on
plume
seg-
ments
in line
of
sight
NXX=
(NX-NXIN),
(NX-1)
PLMAX
Change in I(λ) for
each plume segment
r_p - Distance
from obser-
ver to plume
PLMAX
Change in I(λ) for
atmosphere between
observer and plume
CHROMA
Calculate
reduction in
visual range
24
25
23
22
21
27
26

Figure 13c (continued)

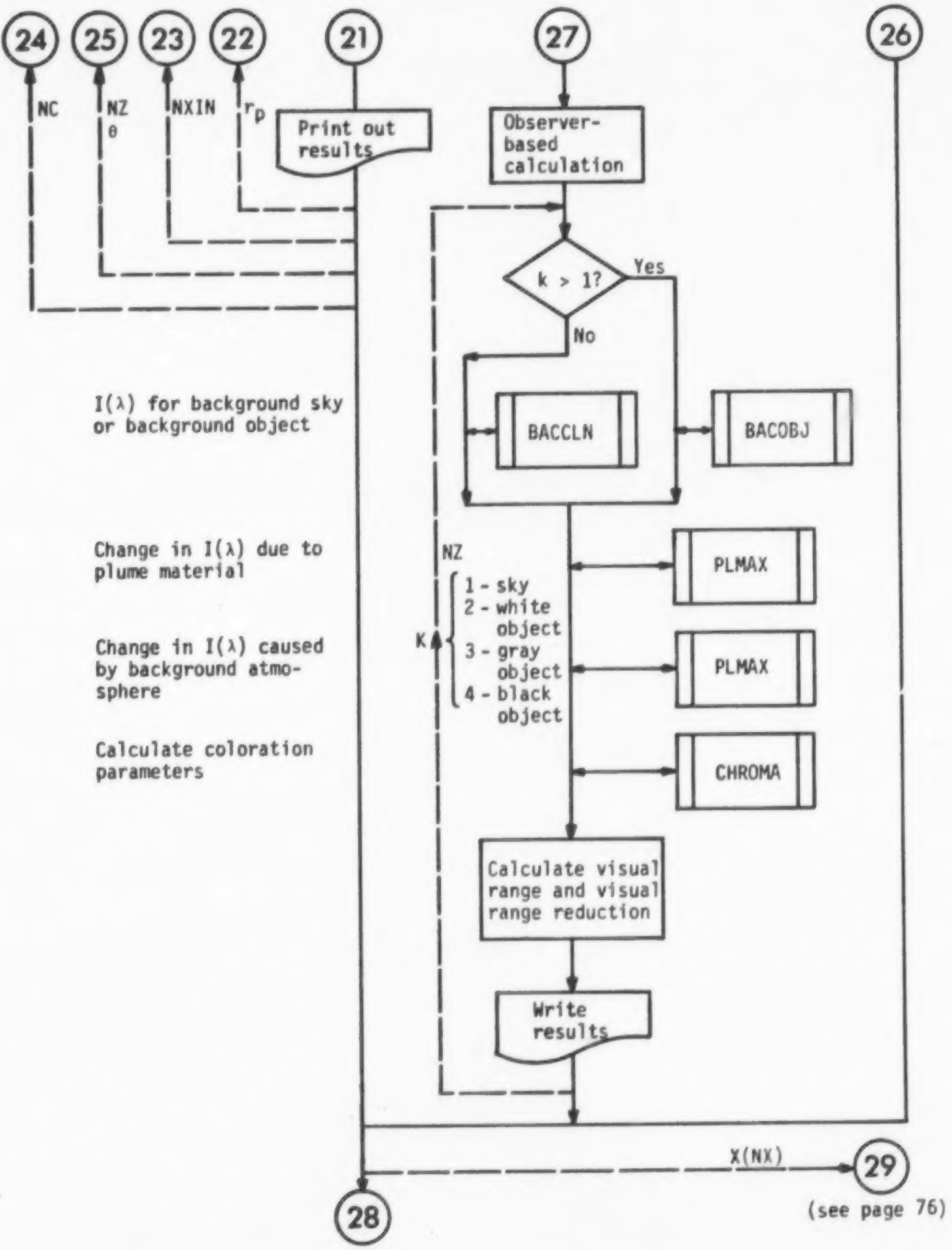

24
25
23
22
21
27
26
NC
NZ
θ
NXIN
r_p
Print out results
Observer-based calculation
k > 1?
Yes
No
I(λ) for background sky or background object
BACCLN
BACOBJ
Change in I(λ) due to plume material
NZ
1 - sky
2 - white object
3 - gray object
4 - black object
K
PLMAX
Change in I(λ) caused by background atmosphere
PLMAX
Calculate coloration parameters
CHROMA
Calculate visual range and visual range reduction
Write results
X(NX)
29
(see page 76)
28

Figure 13c (continued)

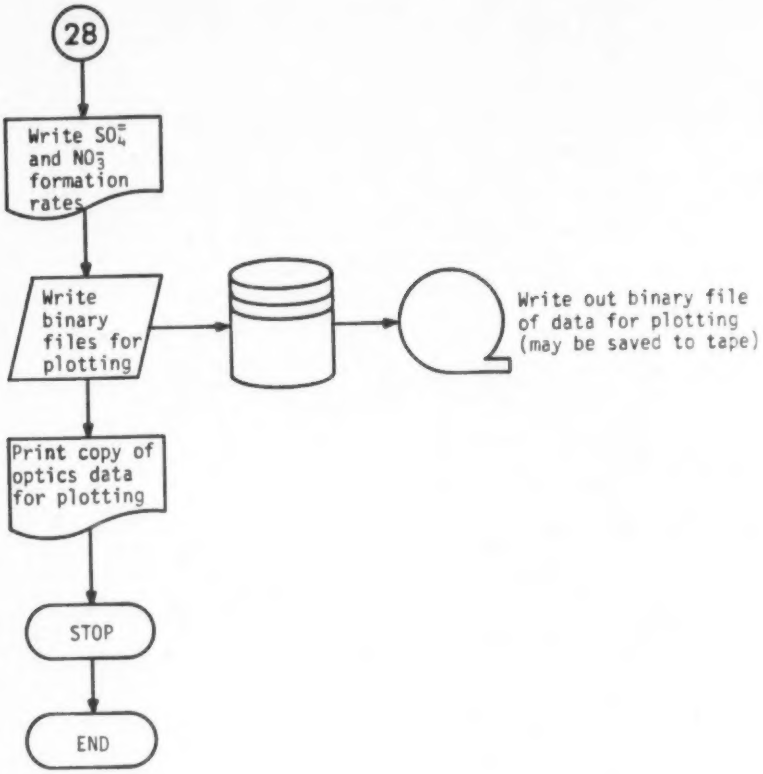
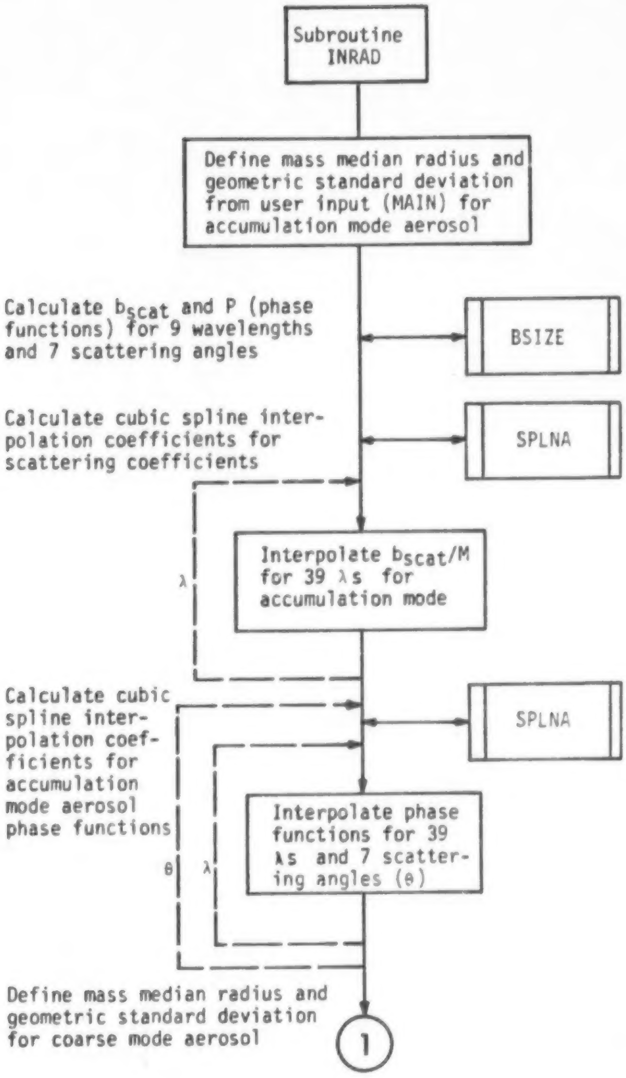

28
Write $SO_4^=$ and NO_3^- formation rates
Write binary files for plotting
Write out binary file of data for plotting (may be saved to tape)
Print copy of optics data for plotting
STOP
END

Figure 13c (concluded)


Subroutine INRAD
Define mass median radius and geometric standard deviation from user input (MAIN) for accumulation mode aerosol
Calculate b_{scat} and P (phase functions) for 9 wavelengths and 7 scattering angles
BSIZE
Calculate cubic spline interpolation coefficients for scattering coefficients
SPLNA
λ
Interpolate b_{scat}/M for 39 λs for accumulation mode
Calculate cubic spline interpolation coefficients for accumulation mode aerosol phase functions
SPLNA
θ
λ
Interpolate phase functions for 39 λs and 7 scattering angles (θ)
Define mass median radius and geometric standard deviation for coarse mode aerosol
1

(d) Flow chart of subroutine INRAD.

Figure 13 (continued)

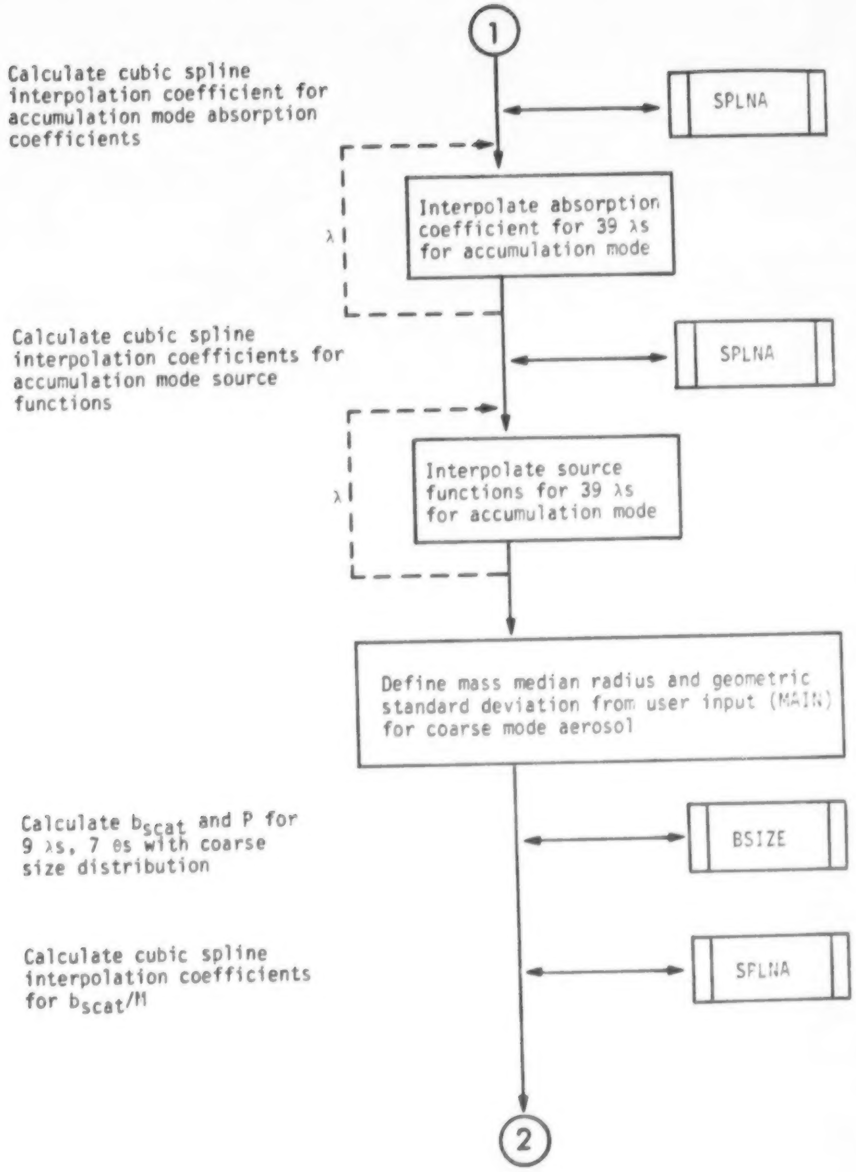

1
Calculate cubic spline interpolation coefficient for accumulation mode absorption coefficients
SPLNA
λ
Interpolate absorption coefficient for 39 λs for accumulation mode
Calculate cubic spline interpolation coefficients for accumulation mode source functions
SPLNA
λ
Interpolate source functions for 39 λs for accumulation mode
Define mass median radius and geometric standard deviation from user input (MAIN) for coarse mode aerosol
Calculate b_{scat} and P for 9 λs, 7 θs with coarse size distribution
BSIZE
Calculate cubic spline interpolation coefficients for b_{scat}/M
SPLNA
2

Figure 13d (continued)

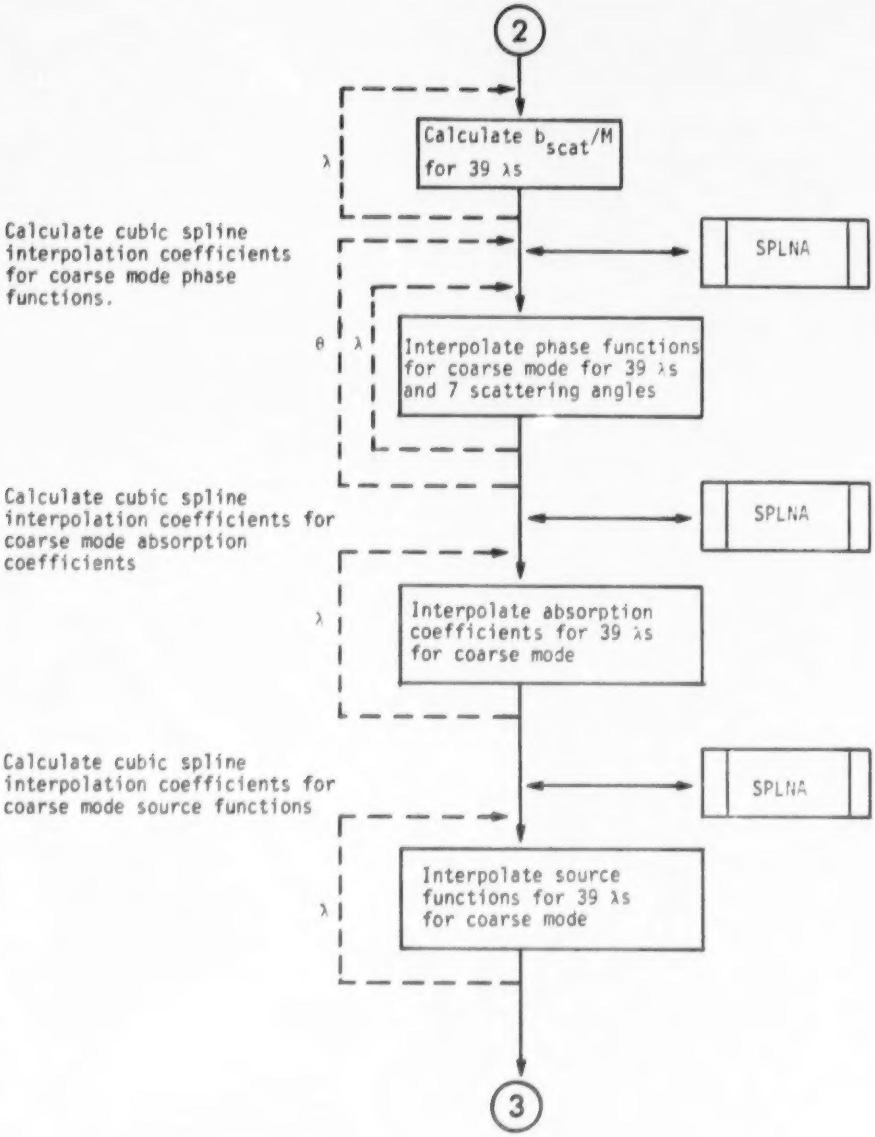

2
Calculate b_{scat}/M for 39 λs
λ
Calculate cubic spline interpolation coefficients for coarse mode phase functions.
SPLNA
θ
λ
Interpolate phase functions for coarse mode for 39 λs and 7 scattering angles
Calculate cubic spline interpolation coefficients for coarse mode absorption coefficients
SPLNA
λ
Interpolate absorption coefficients for 39 λs for coarse mode
Calculate cubic spline interpolation coefficients for coarse mode source functions
SPLNA
λ
Interpolate source functions for 39 λs for coarse mode
3

Figure 13d (continued)

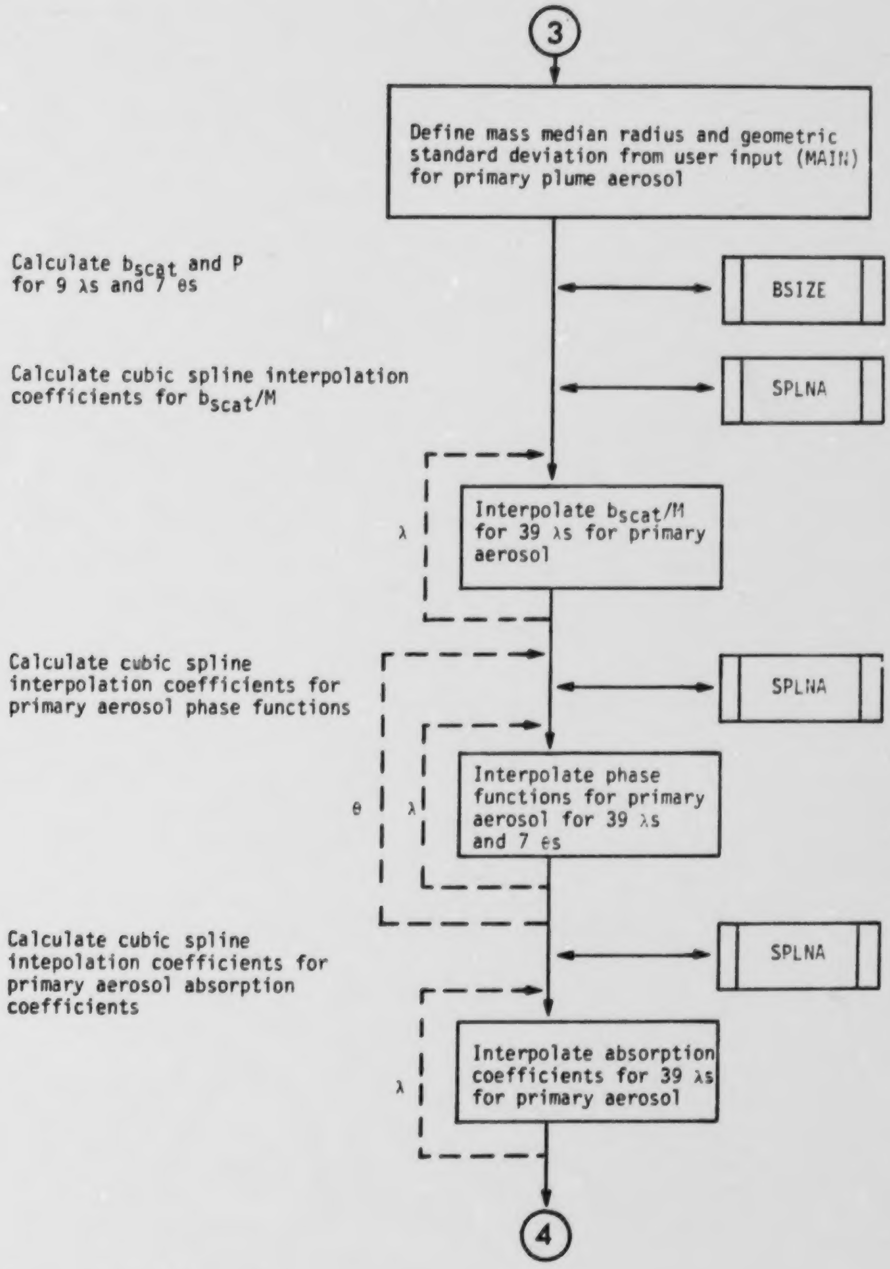

3
Define mass median radius and geometric standard deviation from user input (MAIN) for primary plume aerosol
Calculate b_{scat} and P for 9 λs and 7 θs
BSIZE
Calculate cubic spline interpolation coefficients for b_{scat}/M
SPLNA
λ
Interpolate b_{scat}/M for 39 λs for primary aerosol
Calculate cubic spline interpolation coefficients for primary aerosol phase functions
SPLNA
θ
λ
Interpolate phase functions for primary aerosol for 39 λs and 7 θs
Calculate cubic spline intepolation coefficients for primary aerosol absorption coefficients
SPLNA
λ
Interpolate absorption coefficients for 39 λs for primary aerosol
4

Figure 13d (continued)

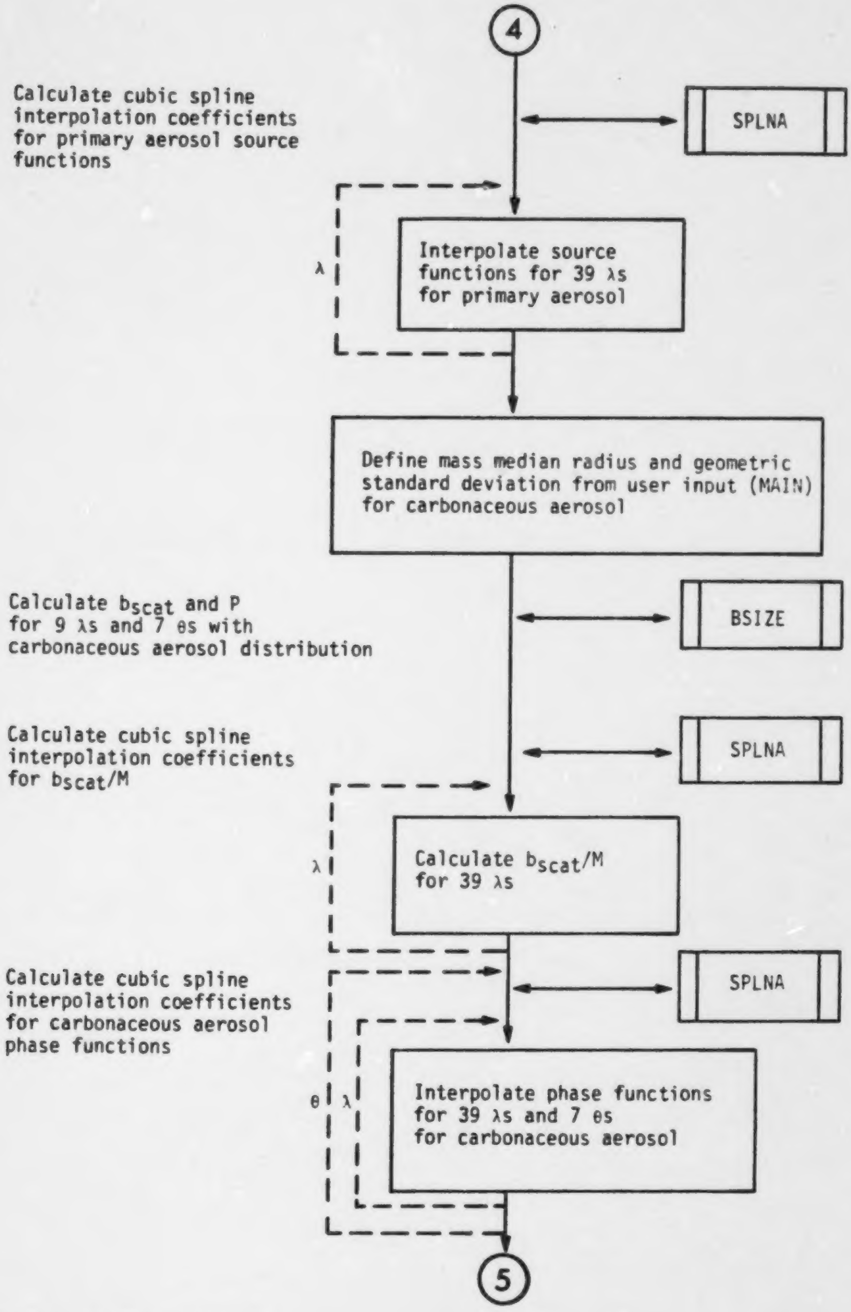

4
Calculate cubic spline interpolation coefficients for primary aerosol source functions
SPLNA
λ
Interpolate source functions for 39 λs for primary aerosol
Define mass median radius and geometric standard deviation from user input (MAIN) for carbonaceous aerosol
Calculate b_{scat} and P for 9 λs and 7 θs with carbonaceous aerosol distribution
BSIZE
Calculate cubic spline interpolation coefficients for b_{scat}/M
SPLNA
λ
Calculate b_{scat}/M for 39 λs
Calculate cubic spline interpolation coefficients for carbonaceous aerosol phase functions
SPLNA
θ
λ
Interpolate phase functions for 39 λs and 7 θs for carbonaceous aerosol
5

Figure 13d (continued)

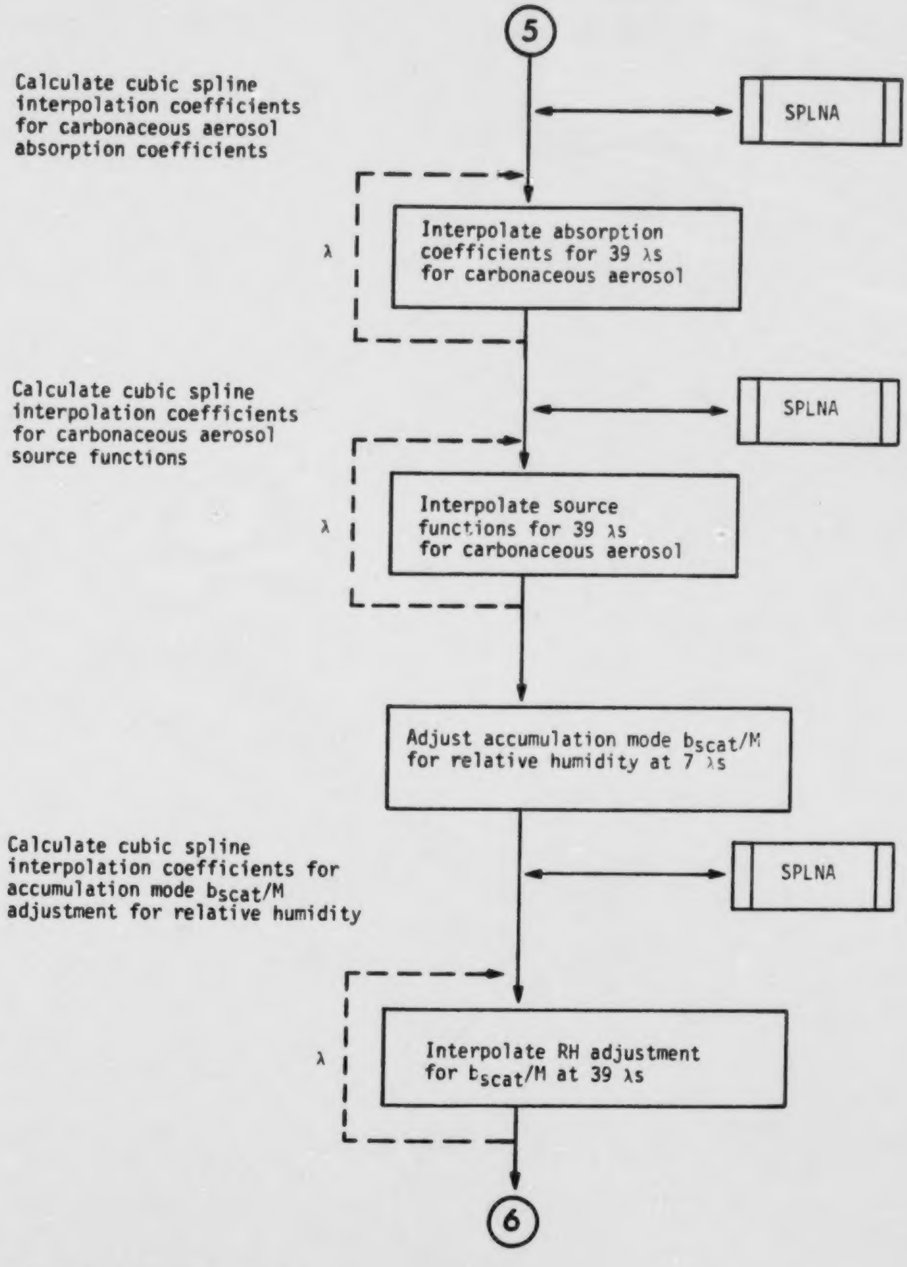

5
Calculate cubic spline interpolation coefficients for carbonaceous aerosol absorption coefficients
SPLNA
λ
Interpolate absorption coefficients for 39 λs for carbonaceous aerosol
Calculate cubic spline interpolation coefficients for carbonaceous aerosol source functions
SPLNA
λ
Interpolate source functions for 39 λs for carbonaceous aerosol
Adjust accumulation mode b_{scat}/M for relative humidity at 7 λs
Calculate cubic spline interpolation coefficients for accumulation mode b_{scat}/M adjustment for relative humidity
SPLNA
λ
Interpolate RH adjustment for b_{scat}/M at 39 λs
6

Figure 13d (continued)

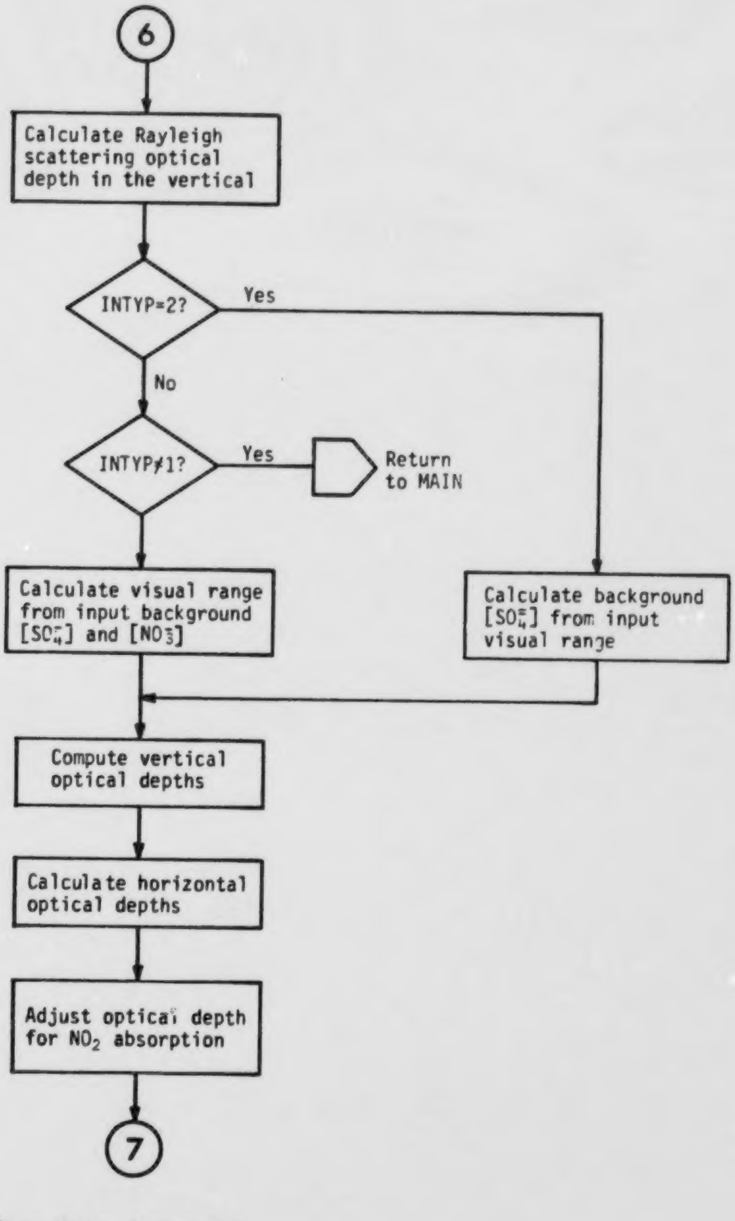
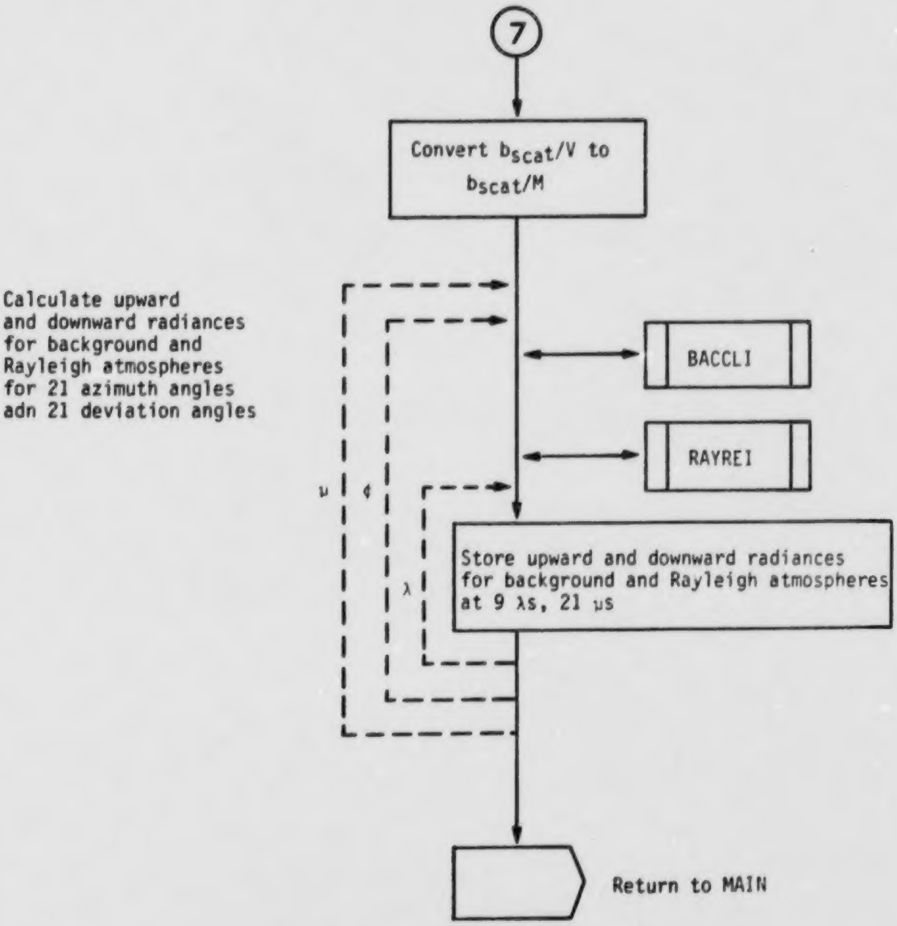
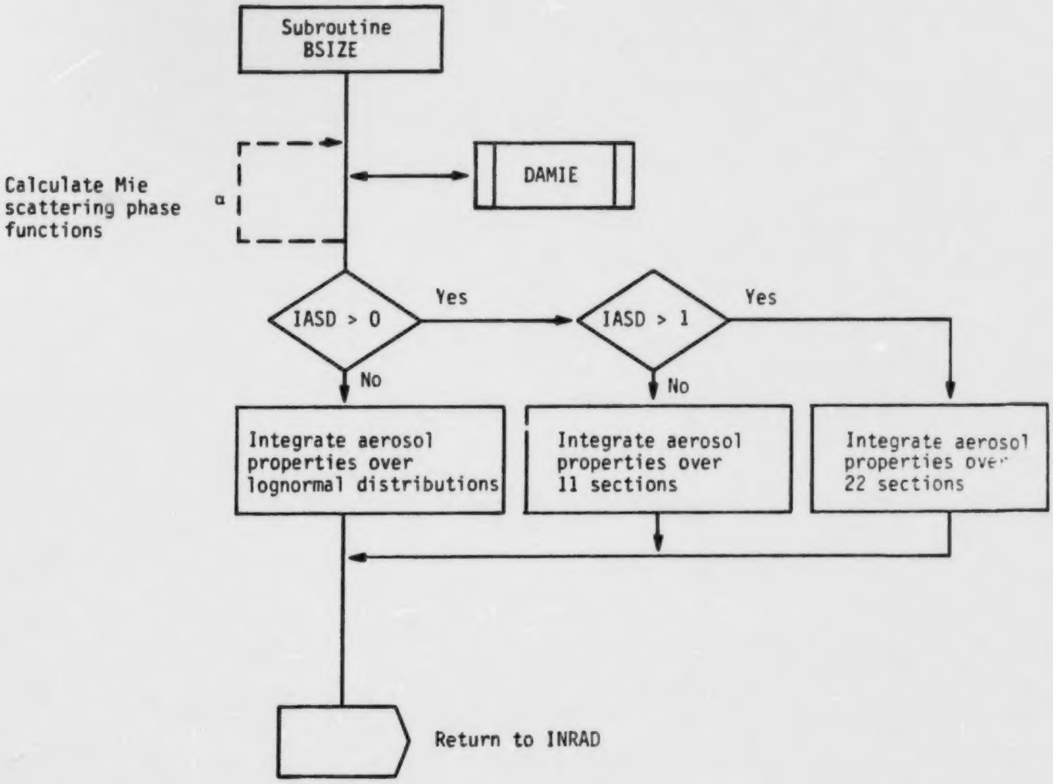

6
Calculate Rayleigh scattering optical depth in the vertical
INTYP=2?
Yes
No
INTYP≠1?
Yes
Return to MAIN
Calculate visual range from input background [SO$_4^=$] and [NO$_3^-$]
Calculate background [SO$_4^=$] from input visual range
Compute vertical optical depths
Calculate horizontal optical depths
Adjust optical depth for NO$_2$ absorption
7

Figure 13d (continued)



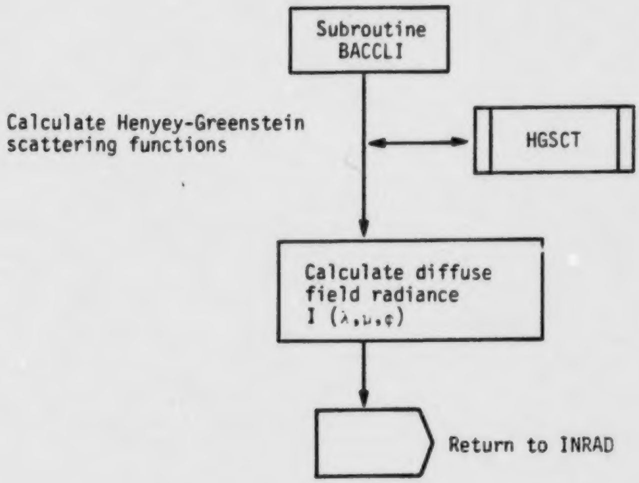
7
Convert b_{scat}/V to b_{scat}/M
Calculate upward and downward radiances for background and Rayleigh atmospheres for 21 azimuth angles adn 21 deviation angles
BACCLI
RAYREI
μ
ϕ
λ
Store upward and downward radiances for background and Rayleigh atmospheres at 9 λs, 21 μs
Return to MAIN

Figure 13d (concluded)


Subroutine BSIZE
Calculate Mie scattering phase functions
α
DAMIE
IASD > 0
Yes
No
IASD > 1
Yes
No
Integrate aerosol properties over lognormal distributions
Integrate aerosol properties over 11 sections
Integrate aerosol properties over 22 sections
Return to INRAD

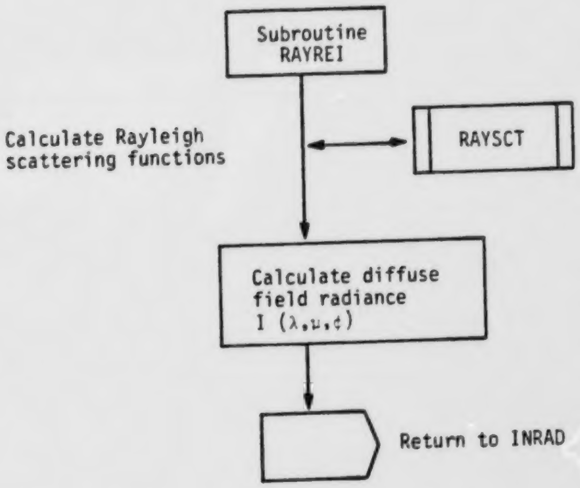
(e) Flow chart of subroutine BSIZE

Figure 13 (continued)


Subroutine BACCLI
Calculate Henyey-Greenstein scattering functions
HGSCT
Calculate diffuse field radiance I (λ,μ,φ)
Return to INRAD

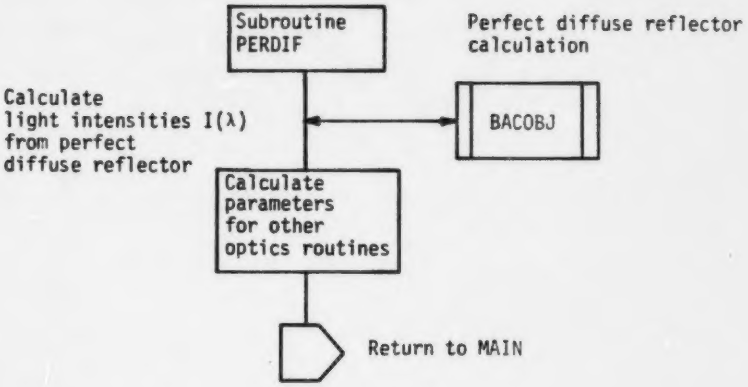
(f) Flow chart of subroutine BACCLI

Figure 13 (continued)


Subroutine RAYREI
Calculate Rayleigh scattering functions
RAYSCT
Calculate diffuse field radiance I (λ,μ,φ)
Return to INRAD

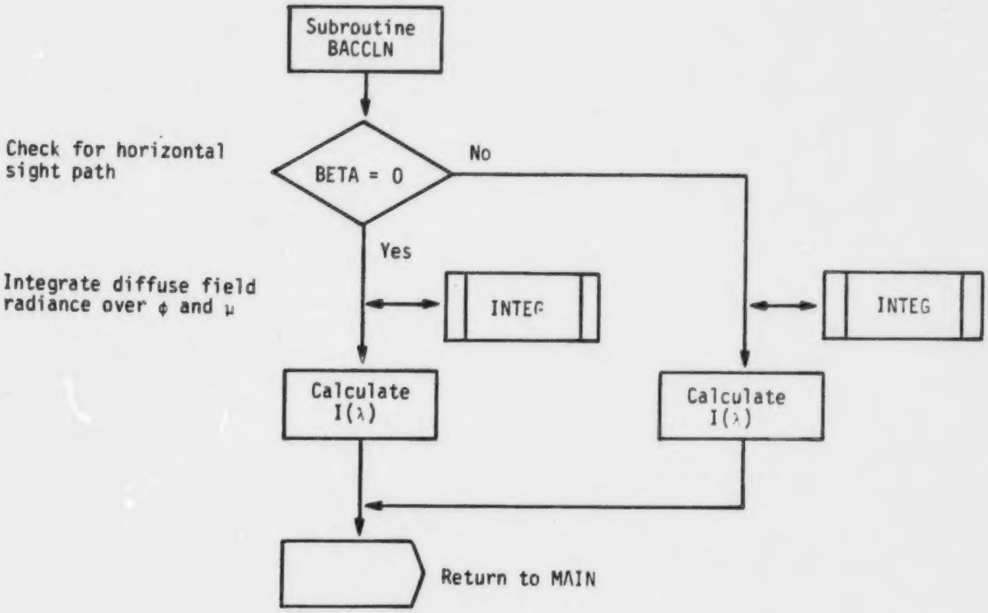
(g) Flow chart of subroutine RAYREI

Figure 13 (continued)


Subroutine
PERDIF
Perfect diffuse reflector
calculation
Calculate
light intensities I(λ)
from perfect
diffuse reflector
BACOBJ
Calculate
parameters
for other
optics routines
Return to MAIN

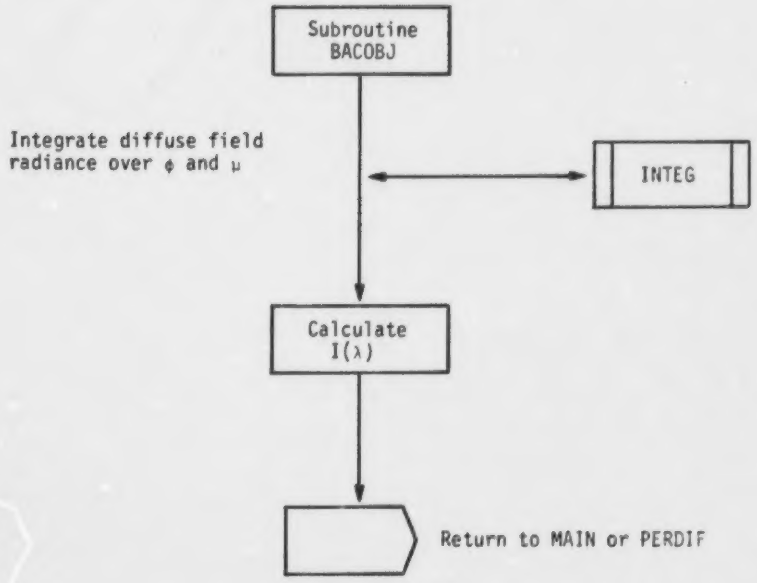
(h) Flow chart of subroutine PERDIF

Figure 13 (continued)


Subroutine BACCLN
Check for horizontal sight path
BETA = 0
No
Yes
Integrate diffuse field radiance over ϕ and μ
INTEG
INTEG
Calculate I(λ)
Calculate I(λ)
Return to MAIN

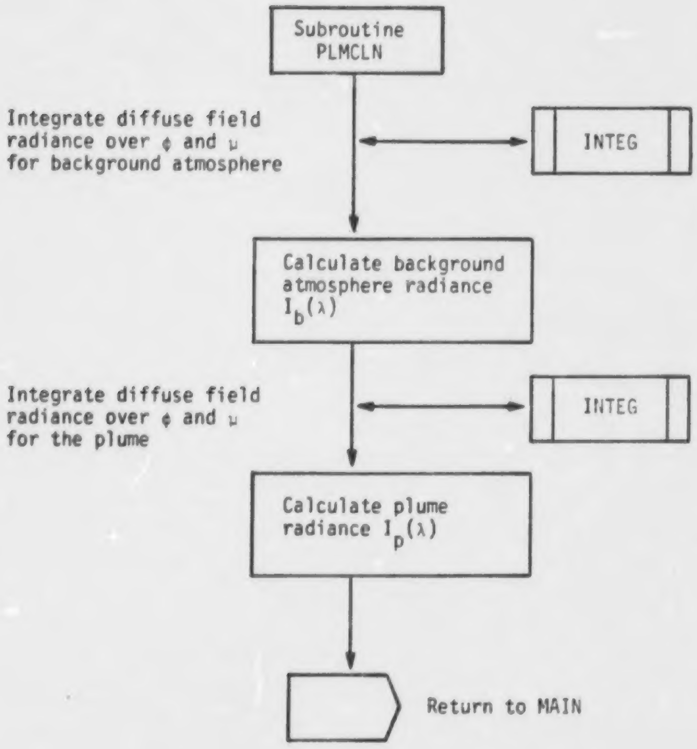
(i) Flow chart of subroutine BACCLN

Figure 13 (continued)


Subroutine BACOBJ
Integrate diffuse field radiance over ϕ and μ
INTEG
Calculate I(λ)
Return to MAIN or PERDIF

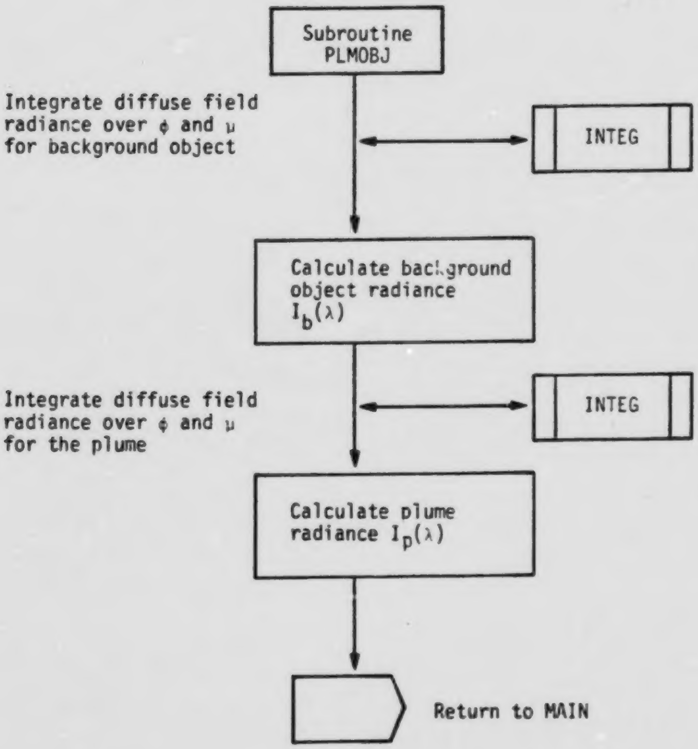
(j) Flow chart of subroutine BACOBJ

Figure 13 (continued)


Subroutine PLMCLN
Integrate diffuse field radiance over φ and μ for background atmosphere
INTEG
Calculate background atmosphere radiance $I_b(\lambda)$
Integrate diffuse field radiance over φ and μ for the plume
INTEG
Calculate plume radiance $I_p(\lambda)$
Return to MAIN

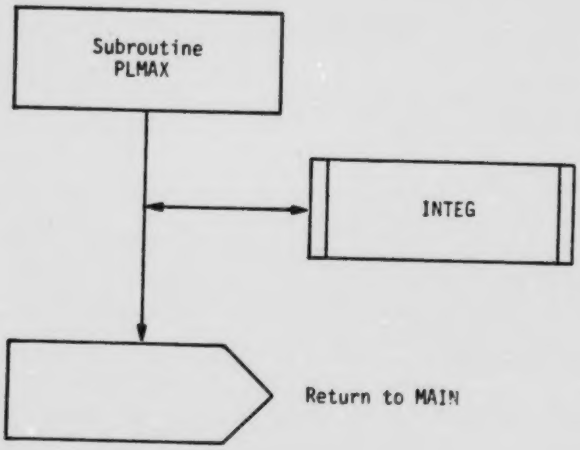
(k) Flow chart of subroutine PLMCLN

Figure 13 (continued)


Subroutine PLMOBJ
Integrate diffuse field radiance over ϕ and μ for background object
INTEG
Calculate background object radiance $I_b(\lambda)$
Integrate diffuse field radiance over ϕ and μ for the plume
INTEG
Calculate plume radiance $I_p(\lambda)$
Return to MAIN

(1) Flow chart of subroutine PLMOBJ

Figure 13 (continued)


Subroutine
PLMAX
INTEG
Return to MAIN

(m) Flow chart of subroutine PLMAX

Figure 13 (concluded)

The optical properties of the aerosol population are calculated by integrating the desired values (extinction, scattering, and absorption coefficients) over the aerosol distribution. The subroutine now offers two options:

> Integration over a lognormal size distribution.
> Integration over a sectional size distribution.

The first option corresponds to the operational version of PLUVUE II, in which the aerosol size distributions are prescribed as lognormal by means of the input median radius and standard deviation. The second option is not operational at the moment, but was included in the code in the event that the aerosol size distributions are input to PLUVUE II in the form of sectional distributions. Thus, PLUVUE II could be coupled with an aerosol plume model such as the Particulate Plume Model (PPM) (Seigneur, 1982; Seigneur, Saxena, and Hudischewskyj, 1982).

The treatment of light absorption by carbonaceous aerosols was implemented in the subroutine INRAD. The calculations of the absorption coefficients for background and plume carbonaceous aerosols are conceptually analogous to the calculation of extinction and scattering coefficients. Concentrations of carbonaceous aerosols, the corresponding lognormal distribution, and the index of refraction are input to the model. From the subroutine INRAD, a call is made to subroutine BSIZE for the calculation of the absorption coefficients integrated over aerosol size distributions.

The treatment of anisotropic multiple scattering required the addition of several subroutines. This treatment is based on the work of Isaacs (1981); its mathematical formulation is presented in detail in Appendix D. The calculation of the initial background diffuse-radiance field GI is performed by subroutines BACCLI and RAYREI, which are based on Isaacs (1981). The calculations of light radiance are performed by subroutines BACCLN (clear sky background), PLMCLN (plume with clear sky background), BACOBJ (background object), PLMOBJ (plume with background object), and RAYREF (Rayleigh atmosphere).

In the original PLUVUE, the isotropic diffuse field was computed in these subroutines by means of an analytical formula. In PLUVUE II, the multiple-scattering calculation is performed by subroutine INTEG. This subroutine calculates the multiple-scattering integral, which requires values of the phase functions and an initial value of the diffuse-field radiance for various azimuthal and scattering angles. These values are provided to INTEG by INRAD. The initial diffuse-field radiance is obtained from BACCLI and RAYREI. These calculations are performed by subroutines RAYREI and RAYSCT for the Rayleigh atmosphere cases, and by subroutines BACCLI and HGSCT for the other cases. These subroutines were derived from Isaacs' computer code. Phase functions are calculated by subroutine DAMIE and integrated over the aerosol size distribution by subroutine BSIZE.

GLOSSARY

ABSNO2: The value b_{abs}, the absorption coefficient, for the background atmosphere NO_2 concentration at 0.55 μm.

ACCUMULATION MODE: Aerosol in the size range from 0.1 to 1.0 μm.

ALPHA: The horizontal angle between the plume centerline and the line of sight.

AZIMUTH: The horizontal angle measured clockwise from north to the line of sight.

BETA: The elevation angle of the line of sight above the horizon.

BETA.55/MASS: The value of b_{scat}/M for a particular aerosol concentration and mass distribution at 0.55 μm.

BRATIO: The blue-red luminance ratio used to characterize the wavelength-dependent contrast and plume coloration with respect to the background. This ratio is calculated using the ratio of plume to background intensities at the blue end ($\lambda = 0.4$ μm) and at the red end ($\lambda = 0.7$ μm) of the visible spectrum. If I_p represents the intensity for the view of the background through the plume, and if I_b represents the intensity for the view of the background without the plume, then the blue-red ratio is defined thus:

$$\text{BRATIO} = \frac{I_p(0.4\ \mu m)/I_b(0.4\ \mu m)}{I_p(0.7\ \mu m)/I_b(0.7\ \mu m)}$$

BSP-TOTAL: The value of b_{scat} for plume primary aerosol and sulfate aerosol at 0.55 μm.

BSPSN/BS (%): The ratio between the b_{scat} for sulfate aerosol and the b_{scat} for plume primary aerosol and sulfate aerosol.

BTAAER: The value of b_{scat} for the background atmosphere aerosol at 0.55 μm.

BTABAC: The value of b_{ext}, the extinction coefficient for the background atmosphere, at 0.55 μm. BTABAC is the sum of BTARAY, BTAAER, and ABSNO2.

BTARAY: The value of b_{scat} for the Rayleigh atmosphere at 0.55 μm.

COARSE PARTICLE MODE: Aerosol from 1.0 to 10.0 μm.

C(550): The contrast at 500 nm between the light intensity from the plume and the intensity of the background. The contrast is calculated by the following equation:

$$C(550) = \frac{I_p\ (\lambda = 0.55\ \mu m) - I_b(\lambda = 0.55\ \mu m)}{I_b\ (\lambda = 0.55\ \mu m)}$$

where I_p = light intensity transmitted from the plume, and I_b = light intensity transmitted from the background.

DELL: The difference in the color brightness parameter L* for the view of the background without the plume and the view of the background with the plume.

DELTA H (M): The rise of the plume parcel above the elevation of the point of release, measured in meters.

DELX: The difference in the chromaticity coordinate x for the view of the background without the plume and the view of the background with the plume.

DELY: The difference in the chromaticity coordinate y for the view of the background without the plume and the view of the background with the plume.

DELYCAP: The difference in the color brightness parameter Y for the view of the background without the plume and the view of the background with the plume.

DOWNWIND DISTANCE: Distance from the emissions source to points along the plume trajectory.

E(LAB): The color difference parameter ΔE (L*a*b*) for the view through the plume compared to the background sky. ΔE (L*a*b*) includes changes in chromaticity (represented by a* and b*) and brightness (represented by L*) and was defined in 1976 by the Commission Internationale de l'Eclairage. Its mathematical formulation is given in Latimer et al. (1978).

E(LUV): The color difference parameter $\Delta E(L^*U^*V^*)$, for the view through the plume compared to the background sky. $\Delta E(L^*U^*V^*)$ includes changes in chromaticity (represented by U^* and V^*) and brightness (represented by L^*). It was defined in 1976 by the Commission Internationale de l'Eclairage as one of two parameters that can be used to quantify color difference (the other one is E(LAB)). Its mathematical formulation is given in Latimer et al. (1978).

H: The final height of plume rise.

INCREMENT: The increase in any parameter above the background value.

L: The color brightness parameter L^*. Its mathematical definition is given in Latimer et al. (1978). It is equivalent to the parameter called "value" in the Munsell color system multiplied by 10.

LENGTH: The length of the plume segment in the line of sight along the plume. The plume centerline concentration is integrated over this distance before the optical effects are calculated.

MASS RADIUS: The mass median radius.

NO2T: The total concentration of NO_2 in a plume parcel; the sum of the NO_2 contributed by the plume and the NO_2 contributed by the background air.

NO2-NO EQUIL: The equilibrium ratio of the concentration of NO_2 to the concentration of NO.

NO2/NTOT (MOLE %): The ratio between the concentration of NO_2 and the concentration of all NO_x and NO_3 .

NO3-/NTOT (MOLE %): The ratio between the concentration of NO_3 and the concentration of all NO_x and NO_3 .

NTOT: The concentration total of all nitrogen oxides and nitrates in the plume parcel.

O2 (MOL P): The oxygen concentration in the plume expressed in mole percent.

% REDUCED: The percentage reduction in visual range for the view of the background without the plume and the view of the background with the plume.

PERCEPTION PARAMETER: See E(LAB) and E(LUV).

PRIMARY PARTICLE MODE: The aerosol emitted directly by the source.

PRIMARY ($\mu G/M^3$): The concentration of primary particulate in units of $\mu g/m^3$.

RATIO ACTUAL: The actual ratio of concentrations of NO_2 to NO.

RP: Distance from the observer position to the plume center along the line of sight.

RO/RVO: The ratio between the distance from the observer to the background object and the background visual range.

RP/RVO: The ratio between the distance from the observer to the plume centerline along the line of sight and the background visual range.

RV: The visual range for the line of sight through the plume.

SY: The length representing the vertical standard deviation for a Gaussian plume centerline distribution.

SIGMA: The geometric standard deviation of the aerosol size distribution. Also, the plume standard deviation for the initial plume rise calculation.

SOLAR AZIMUTH ANGLE: The horizontal angle from north to the position of the sun, measured clockwise.

SOLAR ZENITH ANGLE: The vertical angle from directly overhead to the position of the sun.

SO_4 =/STOT (MOLE %): The ratio between the concentration of $SO_4^=$ and the sum of the concentrations of SO_2, SO_3, and $SO_4^=$.

THETA: The scattering angle between the incoming direct solar rays and the line from the observed point on the plume to the observer position.

TOTAL AMB: The total of the background contribution and the plume contribution for any parameter.

U: Horizontal velocity component for the plume parcel.

V: The speed of the plume parcel.

W: Vertical velocity component for the plume parcel.

X: Distance downwind between the observed point and the emissions source; also used for chromaticity coordinate x.

Y: Chromaticity coordinate y.

YCAP: The color brightness parameter Y.

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APPENDIX A

SAMPLE PLUVUE II SIMULATION
(OBSERVER-BASED)

INPUT DATA FILE

```
VISTTA 81 - CASE 8                                                                                   PAGE    1


VISTTA 81 - CASE 8
 19.3     4-4.0
000417
0.0          0.0
10000.0
56.
    0
 1 0 0 0 6 1 7 1
 1
1.0          2.0          5.0          10.0        15.0        20.4
     500.00       10.00       100.00
   900948.6       302.0         7.0        19.0
   1.0550.0
       72.7
      0.000       0.000       0.038       0.000
      0.140       9.000       0.160       4.500
      1.500       1.900       1.250       1.150
      1.800       2.000       1.800       2.000
      0.050       2.000       2.000       0.000       0.000
      1.500       0.000       1.500       0.000
      1.500       0.000       2.000       1.000
    10.00
    2
    173.0
1.00 1.00 0.10 0.10
    0
0.0
    2    2
    532.8       3625.3      2506.6
    537.5       3608.7      3210.0
   12    9     080850      7.  1981
        0.0         0.0         0.0         0.0         0.0         0.0
      600.0        600.         600         600.        600.        600.        600.        600.
      600.0        600.         600.        600.        600.        600.        600.        600.
      600.0        600.         600.        600.        600.        600.        600.        600.
      139.0
```

OUTPUT DATA FILE

```
1                                                                                    PAGE    1


1
VISUAL IMPACT ASSESSMENT FOR VISTTA 81 - CASE 8

    EMISSIONS SOURCE DATA

         ELEVATION OF SITE =       3210.   FEET MSL
                                    978.   METERS MSL
         NO. OF UNITS =     1.
         STACK HEIGHT =  550.   FEET
                         168.   METERS
         FLUE GAS FLOW RATE =    900949.   CU FT/MIN
                                  425.14   CU M/SEC
         FLUE GAS TEMPERATURE =       302.   F
                                      423.   K
         FLUE GAS OXYGEN CONTENT =         7.0  MOL PERCENT
         SO2 EMISSION RATE (TOTAL) =     500.00   TONS/DAY
                                       5.250E 03   G/SEC
         NOX EMISSION RATE (TOTAL,AS NO2) =      10.00   TONS/DAY
                                             1.050E 02   G/SEC
         PARTICULATE EMISSION RATE (TOTAL) =     100.00   TONS/DAY
1                                            1.050E 03   G/SEC



    METEOROLOGICAL AND AMBIENT AIR QUALITY DATA

         WINDSPEED =  19.3  MILES/HR
                       8.6  M/SEC

         PASQUILL-GIFFORD-TURNER STABILITY CATEGORY D

         LAPSE RATE = -4.00  F/1000 FT
                   -7.291E-03  K/M
         POTENTIAL TEMPERATURE LAPSE RATE =    2.509E-03  K/M
         AMBIENT TEMPERATURE =  72.7  F
                               295.8  K
         RELATIVE HUMIDITY =  56.0  %
         MIXING DEPTH = $1000  M
         AMBIENT PRESSURE =  0.89  ATM

         BACKGROUND NOX CONCENTRATION =       0.000  PPM

         BACKGROUND NO2 CONCENTRATION =       0.000  PPM

         BACKGROUND OZONE CONCENTRATION =       0.038  PPM

         BACKGROUND SO2 CONCENTRATION =       0.000  PPM


         BACKGROUND COARSE MODE CONCENTRATION =        10.0  UG/M3
         BACKGROUND SULFATE CONCENTRATION =        3.0  UG/M3
         BACKGROUND NITRATE CONCENTRATION =        0.0  UG/M3
         BACKGROUND VISUAL RANGE =       173.0  KILOMETERS
         SO2 DEPOSITION VELOCITY =        1.00  CM/SEC
         NOX DEPOSITION VELOCITY =        1.00  CM/SEC
         COARSE PARTICULATE DEPOSITION VELOCITY =       0.10  CM/SEC
```

```
          COARSE PARTICULATE DEPOSITION VELOCITY =        0.10  CM/SEC


 1
                                                                                          PAGE    2


          SUBMICRON PARTICULATE DEPOSITION VELOCITY =        0.10  CM/SEC

                                       AEROSOL STATISTICS

                                   BACKGROUND                                   PLUME

          MASS MEDIAN      ACCUMULATION        COARSE          ACCUMULATION        COARSE          CARBONACEOUS
          RADIUS               MODE              MODE              MODE              MODE               AEROSOLS
          MICROMETERS          0.140             9.000             0.160             4.500             0.050

          GEOMETRIC
          STANDARD
          DEVIATION            1.500             1.900             1.250             1.150             2.000

          PARTICLE
          DENSITY
          G/(CM**3)            1.800             2.000             1.800             2.000             2.000
 CARBONACEOUS FRACTION OF PARTICLATE MASS EMISSIONS =       0.000
 BACKGROUND ATMOSPHERIC ELEMENTAL CARBON =       0.000 UG/M**3
 1


     GEOMETRY OF USER-SPECIFIED PLUME-OBSERVER-SUN ORIENTATION

          WIND DIRECTION (DEGREES) =139.0

          SIMULATION IS FOR  850.  HOURS ON  9/ 8
          SOLAR ZENITH ANGLE (DEGREES) = 55.6
          SOLAR AZIMUTH ANGLE (DEGREES) =   107.0


          GEOMETRIES FOR LINES-OF-SIGHT THROUGH PLUME PARCELS AT GIVEN DOWNWIND DISTANCES (X)

   X (KM)   AZIMUTH       RP       ALPHA       BETA      THETA
     1.0     165.7      16.4       26.7        2.1       63.3
     2.0     167.3      15.5       28.3        2.2       64.5
     5.0     173.7      12.9       34.7        2.6       69.3
    10.0     191.6       9.3       52.6        3.7       83.4
    15.0     224.2       7.4       85.2        4.6      109.3
    20.4     262.1       8.8       56.9        3.9      135.1
 1                                BACKGROUND CONDITIONS

   ACCUMULATION MODE                            COARSE PARTICLE MODE                            PRIMARY PARTICLE MODE
   MASS RADIUS     SIGMA     BSCAT.55/MASS        MASS RADIUS     SIGMA     BSCAT.55/MASS         MASS RADIUS     SIGMA     BSCAT.55/MASS
  0.1400E 00    0.1500E 01    0.4201E-02          0.9000E 01    0.1900E 01    0.1096E-03          0.4500E 01    0.1150E 01    0.1844E-03


                                              REFRACTION INDEXES

   ACCUMULATION MODE       =     0.1500E 01 + I     0.0000E 00
   COARSE MODE             =     0.1500E 01 + I     0.0000E 00
   PRIMARY AEROSOLS        =     0.1500E 01 + I     0.0000E 00
   CARBONACEOUS AEROSOLS =       0.2000E 01 + I     0.1000E 01
```

```
1                                                                                                    PAGE    3

                             COEFFICIENTS AT 0.55 MICROMETERS , 1./KM
              BTARAY =0.1052E-01   BTAAER =0.1363E-01   ABSNO2 =0.0000E 00   BTABAC =0.2261E-01
1
                                           INITIAL PLUME RISE AND DILUTION AND NITROGEN DIOXIDE FORMATION

                                                    VISTTA 81 - CASE 8

  TIME       X      DELTA H     U        W        V     SIGMA     TEMP      O2     NO2-NO RATIO     NOX       NO       NO2T     SO2     PARTICULATE
 (SEC)      (M)      (M)     (M/S)    (M/S)    (M/S)     (M)      (K)     MOL P   EQUIL    ACTUAL   (PPM)     (PPM)    (PPM)    (PPM)    UG/M3
   0.       0.0      0.0     8.63    19.00    19.00      0.0    423.1      7.0 1.4E 03 3.6E-03 208.594 207.849   0.7467498.021   3.92E 06
  10.      86.3     20.2     8.63     2.71     9.04      4.7    329.4     17.3 1.6E 05 5.6E-03  55.089  54.782   0.3081980.208   1.04E 06
  20.     172.5     32.1     8.63     2.19     8.90      7.5    308.5     19.6 4.4E 05 7.5E-03  20.802  20.648   0.155 747.752   3.91E 05
  30.     258.8     42.0     8.63     1.92     8.84      9.8    303.1     20.1 5.6E 05 8.4E-03  11.987  11.887   0.100 430.860   2.26E 05
  40.     345.1     50.9     8.63     1.75     8.80     11.8    300.7     20.4 6.3E 05 8.9E-03   8.137   8.065   0.072 292.494   1.53E 05
  50.     431.4     59.1     8.63     1.63     8.78     13.7    299.4     20.5 6.7E 05 9.3E-03   6.033   5.978   0.056 216.874   1.14E 05
  60.     517.6     66.7     8.63     1.53     8.76     15.5    298.6     20.6 7.0E 05 9.6E-03   4.728   4.683   0.045 169.947   8.90E 04
  70.     603.9     73.9     8.63     1.46     8.75     17.2    298.1     20.7 7.2E 05 9.8E-03   3.848   3.811   0.037 138.328   7.24E 04
  80.     690.2     80.8     8.63     1.39     8.74     18.8    297.7     20.7 7.3E 05 1.0E-02   3.220   3.188   0.032 115.753   6.06E 04
  90.     776.4     87.4     8.63     1.34     8.73     20.3    297.4     20.8 7.4E 05 1.0E-02   2.752   2.725   0.028  98.929   5.18E 04
 100.     862.7     93.8     8.63     1.29     8.72     21.8    297.2     20.8 7.5E 05 1.0E-02   2.392   2.367   0.024  85.968   4.50E 04
 110.     949.0     99.9     8.63     1.25     8.72     23.2    297.0     20.8 7.5E 05 1.0E-02   2.106   2.085   0.022  75.715   3.96E 04
1
                                   CONCENTRATIONS OF AEROSOL AND GASES CONTRIBUTED BY

                                             VISTTA 81 - CASE 8
 DOWNWIND DISTANCE (KM) =     1.0
 PLUME ALTITUDE (M)     =   382.
 SIGMA Y (M)            =    67.
 SIGMA Z (M)            =    31.
 SO2-SO4 CONVERSION RATE=       0.0000 PERCENT/HR
 NOX-NO3 CONVERSION RATE=       0.0000 PERCENT/HR

 ALTITUDE           NOX        NO2         NO3-   NO2/NTOT  NO3-/NTOT       SO2        SO4=  SO4=/STOT       O3     PRIMARY BSP-TOTAL   BSPSN/BS
                   (PPM)      (PPM)       (PPM)   (MOLE %)   (MOLE %)      (PPM)    (UG/M3)  (MOLE %)      (PPM)     (UG/M3) (10-4 M-1)    (%)
  H+2S
 INCREMENT!        0.074      0.030       0.000    40.372     0.000        2.669     0.000     0.000      -0.029   1397.156     2.577      0.000
 TOTAL AMB!        0.074      0.030       0.000    40.372     0.000        2.669     2.983     0.028       0.009   1410.139     2.713      4.620
  H+1S
 INCREMENT!        0.333      0.040       0.000    11.930     0.000       11.963     0.000     0.000      -0.036   6261.617    11.548      0.000
 TOTAL AMB!        0.333      0.040       0.000    11.930     0.000       11.963     2.983     0.006       0.002   6274.600    11.684      1.073
  H
 INCREMENT!        0.549      0.043       0.000     7.767     0.000       19.723     0.000     0.000      -0.037  10323.662    19.040      0.000
 TOTAL AMB!        0.549      0.043       0.000     7.767     0.000       19.723     2.983     0.004       0.001  10336.645    19.176      0.654
  H-1S
 INCREMENT!        0.333      0.040       0 000    11.930     0.000       11.963     0.000     0.000      -0.036   6261.617    11.548      0.000
 TOTAL AMB!        0.333      0.040       0.000    11.930     0.000       11.963     2.983     0.006       0.002   6274.600    11.684      1.073
  H-2S
 INCREMENT!        0.074      0.030       0.000    40.372     0.000        2.669     0.000     0.000      -0.029   1397.156     2.577      0.000
 TOTAL AMB!        0.074      0.030       0.000    40.372     0.000        2.669     2.983     0.028       0.009   1410.139     2.713      4.620
   0
 INCREMENT!        0.000      0.000       0.000     0.000     0.000        0.000     0.000     0.000       0.000      0.000     0.000      0.000
 TOTAL AMB!        0.000      0.000       0.000   100.000     0.000        0.000     2.983   100.000       0.038    .12.983     0.136     91.957


 CUMULATIVE SURFACE DEPOSITION (MOLE FRACTION OF INITIAL FLUX)
CUMULATIVE SURFACE DEPOSITION (MOLE FRACTION OF INITIAL FLUX)

1                                                                                   PAGE   4

                   SO2!     0.0000
                   NOX!     0.0000
   PRIMARY PARTICULATE!     0.0000
                   SO4!     0.0000
                   NO3!     0.0000
1
                    VISUAL EFFECTS FOR HORIZONTAL SIGHT PATHS
                    VISTTA 81 - CASE 8
   DOWNWIND DISTANCE (KM) =     1.0
   PLUME ALTITUDE (M)      =   382.
   PLUME-OBSERVER DISTANCE (KM) =   16.4
   AZIMUTH OF LINE-OF-SIGHT =  165.7
   ELEVATION ANGLE OF LINE-OF-SIGHT =     2.1
   SOLAR ZENITH ANGLE =   55.6   AT  850.  ON  9/ 8
   SIGHT PATH IS THROUGH PLUME CENTER
   THETA ALPHA  RP/RVO     RV  %REDUCED     YCAP        L        X         Y DELYCAP     DELL  C(550)  BRATIO     DELX     DELY  E(LUV)  E(LAB)

     63.
          27.    0.09   147.2   14.93   57.04   80.22  0.3109  0.3265   -8.65    -4.63 -0.1318  1.1085 -0.0064 -0.0068  6.8256  5.626
1
          PLUME VISUAL EFFECTS FOR HORIZONTAL VIEWS
          OF THE PLUME OF WHITE, GRAY, AND BLACK OBJECTS
          FOR SPECIFIC OBSERVER-PLUME AND OBSERVER-OBJECT DISTANCES

          VISTTA 81 - CASE 8

   DOWNWIND DISTANCE (KM) =     1.0
   PLUME-OBSERVER DISTANCE (KM) =   16.4
   AZIMUTH OF LINE-OF-SIGHT =  165.7
   ELEVATION ANGLE OF LINE-OF-SIGHT =     2.1
   SOLAR ZENITH ANGLE =    55.6   AT  850.  ON  9/ 8
   THETA =    63.

   REFLECT  RP/RVO  RO/RVO    YCAP       L        X         Y DELYCAP     DELL  C(550)   BRATIO     DELX     DELY  E(LUV)   E(LAB)
       1.0    0.09    3.47   32.16   63.50  0.3323  0.3379  -34.59   -21.89 -0.5252   0.6803   0.0162   0.0072 23.9541 22.6341
       0.3    0.09    3.47   32.16   63.50  0.3323  0.3379  -34.59   -21.89 -0.5252   0.6803   0.0162   0.0072 23.9545 22.6342
       0.0    0.09    3.47   32.16   63.50  0.3323  0.3379  -34.58   -21.89 -0.5252   0.6802   0.0162   0.0072 23.9546 22.6342
1
                    CONCENTRATIONS OF AEROSOL AND GASES CONTRIBUTED BY

                              VISTTA 81 - CASE 8
   DOWNWIND DISTANCE (KM) =     2.0
   PLUME ALTITUDE (M)      =   382.
   SIGMA Y (M)             =   128.
   SIGMA Z (M)             =    50.
   SO2-SO4 CONVERSION RATE=      0.0000 PERCENT/HR
   NOX-NO3 CONVERSION RATE=      0.0002 PERCENT/HR

   ALTITUDE         NOX      NO2      NO3-  NO2/NTOT  NO3-/NTOT      SO2      SO4=  SO4=/STOT      O3    PRIMARY BSP-TOTAL  BSPSN/BS
                  (PPM)    (PPM)    (PPM)  (MOLE %)  (MOLE %)     (PPM)   (UG/M3)  (MOLE %)    (PPM)    (UG/M3) (10-4 M-1)    (%)
    H+2S
   INCREMENT!     0.024    0.015    0.000    63.763     0.000     0.868     0.002     0.000   -0.015    454.431     0.838     0.010
   TOTAL AMB!     0.024    0.015    0.000    63.763     0.000     0.868     2.985     0.088    0.023    467.414     0.974    12.870
    H+1S
   INCREMENT!     0.108    0.033    0.000    30.818     0.000     3.891     0.000     0.000   -0.032   2036.616     3.756     0.000
   TOTAL AMB!     0.108    0.033    0.000    30.818     0.000     3.891     2.984     0.020    0.006   2049.600     3.892     3.220
    H
   INCREMENT!     0.178    0.037    0.000    20.487     0.000     6.415     0.000     0.000   -0.035   3357.813     6.193     0.000
```

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1                                                                                                                  PAGE    5

 TOTAL AMB!      0.178     0.037     0.000    20.487     0.000     6.415     2.984     0.012     0.003  3370.796     6.329     1.981
  H-1S
 INCREMENT!      0.108     0.033     0.000    30.818     0.000     3.891     0.000     0.000    -0.032  2036.615     3.756     0.000
 TOTAL AMB!      0.108     0.033     0.000    30.818     0.000     3.891     2.984     0.020     0.006  2049.598     3.892     3.220
  H-2S
 INCREMENT!      0.024     0.015     0.000    63.763     0.000     0.868     0.002     0.000    -0.015   454.430     0.838     0.010
 TOTAL AMB!      0.024     0.015     0.000    63.763     0.000     0.868     2.985     0.088     0.023   467.413     0.974    12.870
   O
 INCREMENT!      0.000     0.000     0.000     0.000     0.478     0.000     0.000     0.068    -0.000     0.000     0.000    10.445
 TOTAL AMB!      0.000     0.000     0.000    99.522     0.478     0.000     2.983   100.000     0.038    12.983     0.136    91.957


 CUMULATIVE SURFACE DEPOSITION (MOLE FRACTION OF INITIAL FLUX)
                     SO2!    0.0000
                     NOX!    0.0000
 PRIMARY PARTICULATE!    0.0000
                     SO4!    0.0000
                     NO3!    0.0000
1
                  VISUAL EFFECTS FOR HORIZONTAL SIGHT PATHS
                  VISTTA 81 - CASE 8
 DOWNWIND DISTANCE (KM) =     2.0
 PLUME ALTITUDE (M)      =   382.
 PLUME-OBSERVER DISTANCE (KM) =    15.5
 AZIMUTH OF LINE-OF-SIGHT =  167.3
 ELEVATION ANGLE OF LINE-OF-SIGHT =     2.2
 SOLAR ZENITH ANGLE =    55.6    AT   850.  ON   9/ 8
 SIGHT PATH IS THROUGH PLUME CENTER
 THETA ALPHA  RP/RVO    RV  %REDUCED    YCAP       L        X         Y DELYCAP    DELL  C(550)  BRATIO    DELX     DELY  E(LUV)  E(LAB)

   65.
          28.    0.09   158.4    8.42   58.14   80.84  0.3146  0.3307   -6.09   -3.27 -0.0948  1.0589 -0.0021 -0.0021  3.6173  3.414
1
          PLUME VISUAL EFFECTS FOR HORIZONTAL VIEWS
          OF THE PLUME OF WHITE, GRAY, AND BLACK OBJECTS
          FOR SPECIFIC OBSERVER-PLUME AND OBSERVER-OBJECT DISTANCES

          VISTTA 81 - CASE 8

 DOWNWIND DISTANCE (KM) =     2.0
 PLUME-OBSERVER DISTANCE (KM) =    15.5
 AZIMUTH OF LINE-OF-SIGHT =  167.3
 ELEVATION ANGLE OF LINE-OF-SIGHT =     2.2
 SOLAR ZENITH ANGLE =    55.6    AT   850.  ON   9/ 8
 THETA =    65.

 REFLECT  RP/RVO   RO/RVO     YCAP       L        X         Y DELYCAP     DELL  C(550)   BRATIO     DELX      DELY  E(LUV)  E(LAB)
     1.0    0.09     3.47    32.08   63.44  0.3378  0.3522  -33.60   -21.41 -0.5121   0.5613   0.0227   0.0223 26.0255 23.4931
     0.3    0.09     3.47    32.08   63.44  0.3378  0.3522  -33.59   -21.41 -0.5121   0.5614   0.0227   0.0223 26.0255 23.4931
     0.0    0.09     3.47    32.08   63.44  0.3378  0.3522  -33.59   -21.41 -0.5121   0.5614   0.0227   0.0223 26.0256 23.4931
1
                         CONCENTRATIONS OF AEROSOL AND GASES CONTRIBUTED BY

                                 VISTTA 81 - CASE 8
 DOWNWIND DISTANCE (KM) =     5.0
 PLUME ALTITUDE (M)      =   382
PLUME ALTITUDE (M)      =   382.


1                                                                                    PAGE    6


SIGMA Y (M)              =   295.
SIGMA Z (M)              =    90.
SO2-SO4 CONVERSION RATE=        0.0003 PERCENT/HR
NOX-NO3 CONVERSION RATE=        0.0021 PERCENT/HR

ALTITUDE          NOX       NO2        NO3-   NO2/NTOT  NO3-/NTOT      SO2       SO4=  SO4=/STOT      O3     PRIMARY BSP-TOTAL  BSPSN/BS
                 (PPM)     (PPM)      (PPM)   (MOLE %)  (MOLE %)      (PPM)    (UG/M3)  (MOLE %)     (PPM)   (UG/M3) (10-4 M-1)   (%)
 H+2S
INCREMENT!       0.006     0.004      0.000    72.274     0.006      0.209      0.011     0.001     -0.004   109.363     0.202     0.237
TOTAL AMB!       0.006     0.004      0.000    72.274     0.006      0.209      2.995     0.364      0.034   122.347     0.338    37.171
 H+1S
INCREMENT!       0.026     0.016      0.000    62.796     0.000      0.936      0.003     0.000     -0.016   490.132     0.904     0.014
TOTAL AMB!       0.026     0.016      0.000    62.796     0.000      0.936      2.986     0.081      0.022   503.115     1.040    12.060
 H
INCREMENT!       0.043     0.023      0.000    54.030     0.000      1.544      0.002     0.000     -0.023   808.091     1.490     0.005
TOTAL AMB!       0.043     0.023      0.000    54.030     0.000      1.544      2.985     0.049      0.015   821.074     1.627     7.710
 H-1S
INCREMENT!       0.026     0.016      0.000    62.796     0.00C      0.936      0.003     0.000     -0.016   490.132     0.904     0.014
TOTAL AMB!       0.026     0.016      0.000    62.796     0.000      0.936      2.986     0.081      0.022   503.115     1.040    12.060
 H-2S
INCREMENT!       0.006     0.004      0.000    72.274     0.006      0.209      0.011     0.001     -0.004   109.363     0.202     0.237
TOTAL AMB!       0.006     0.004      0.000    72.274     0.006      0.209      2.995     0.364      0.034   122.347     0.338    37.171
 0
INCREMENT!       0.000     0.000      0.000     0.000     1.896      0.000      0.004     0.272     -0.000     0.214     0.001    31.705
TOTAL AMB!       0.000     0.000      0.000    73.117     1.896      0.000      2.988    65.119      0.038    13.197     0.137    91.702


CUMULATIVE SURFACE DEPOSITION (MOLE FRACTION OF INITIAL FLUX)
                SO2!     0.0000
                NOX!     0.0000
PRIMARY PARTICULATE!     0.0000
                SO4!     0.0000
                NO3!     0.0000
1
                     VISUAL EFFECTS FOR HORIZONTAL SIGHT PATHS
                     VISTTA 81 - CASE 8
DOWNWIND DISTANCE (KM) =      5.0
PLUME ALTITUDE (M)      =    382.
PLUME-OBSERVER DISTANCE (KM) =    12.9
AZIMUTH OF LINE-OF-SIGHT =  173.7
ELEVATION ANGLE OF LINE-OF-SIGHT =     2.6
SOLAR ZENITH ANGLE =    55.6   AT  850.  ON   9/ 8
SIGHT PATH IS THROUGH PLUME CENTER
THETA ALPHA  RP/RVO    RV  %REDUCED    YCAP       L       X        Y DELYCAP    DELL  C(550)  BRATIO    DELX    DELY  E(LUV)  E(LAB)

  69.
        35.    0.07   166.5    3.73   56.79   80.08  0.3146  0.3304   -3.35   -1.85 -0.0565  1.0035 -0.0003 -0.0006  1.8763  1.867
1
        PLUME VISUAL EFFECTS FOR HORIZONTAL VIEWS
        OF THE PLUME OF WHITE, GRAY, AND BLACK OBJECTS
        FOR SPECIFIC OBSERVER-PLUME AND OBSERVER-OBJECT DISTANCES

        VISTTA 81 - CASE 8

DOWNWIND DISTANCE (KM) =     5.0
PLUME-OBSERVER DISTANCE (KM) =    12.9
```

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1                                                                                              PAGE    7

AZIMUTH OF LINE-OF-SIGHT =  173.7
ELEVATION ANGLE OF LINE-OF-SIGHT =     2.6
SOLAR ZENITH ANGLE =    55.6   AT  850.  ON   9/ 8
THETA =    69.

REFLECT   RP/RVO   RO/RVO     YCAP       L        X        Y DELYCAP     DELL  C(550)   BRATIO     DELX     DELY  E(LUV)  E(LAB)
    1.0     0.07     3.47    26.80   58.82  0.3410  0.3470  -34.30   -23.63 -0.5713   0.5236   0.0288   0.0199 28.9112 25.7762
    0.3     0.07     3.47    26.80   58.82  0.3410  0.3470  -34.30   -23.63 -0.5713   0.5238   0.0288   0.0199 28.9107 25.7761
    0.0     0.07     3.47    26.80   58.82  0.3410  0.3470  -34.30   -23.63 -0.5713   0.5239   0.0288   0.0199 28.9104 25.7760
1
                     CONCENTRATIONS OF AEROSOL AND GASES CONTRIBUTED BY

                                  VISTTA 81 - CASE 8
DOWNWIND DISTANCE (KM) =    10.0
PLUME ALTITUDE (M)     =    382.
SIGMA Y (M)            =    551.
SIGMA Z (M)            =    136.
SO2-SO4 CONVERSION RATE=       0.0053 PERCENT/HR
NOX-NO3 CONVERSION RATE=       0.0369 PERCENT/HR

ALTITUDE          NOX        NO2        NO3-  NO2/NTOT  NO3-/NTOT      SO2      SO4=  SO4=/STOT      O3    PRIMARY BSP-TOTAL  BSPSN/BS
                (PPM)      (PPM)       (PPM)  (MOLE %)  (MOLE %)     (PPM)   (UG/M3)  (MOLE %)     (PPM)   (UG/M3) (10-4 M-1)   (%)
 H+2S
INCREMENT!      0.002      0.002       0.000    73.702     0.074     0.074     0.043     0.015    -0.002    38.879     0.074     2.467
TOTAL AMB!      0.002      0.002       0.000    73.702     0.074     0.074     3.027     1.027     0.036    51.862     0.210    60.601
 H+1S
INCREMENT!      0.009      0.007       0.000    70.828     0.009     0.333     0.027     0.002    -0.006   174.242     0.322     0.350
TOTAL AMB!      0.009      0.007       0.000    70.828     0.009     0.333     3.010     0.230     0.032   187.225     0.459    27.566
 H
INCREMENT!      0.015      0.010       0.000    68.130     0.003     0.549     0.019     0.001    -0.010   287.276     0.531     0.150
TOTAL AMB!      0.015      0.010       0.000    68.130     0.003     0.549     3.002     0.139     0.028   300.260     0.667    18.913
 H-1S
INCREMENT!      0.009      0.007       0.000    70.827     0.009     0.333     0.027     0.002    -0.006   174.249     0.322     0.350
TOTAL AMB!      0.009      0.007       0.000    70.828     0.009     0.333     3.010     0.230     0.032   187.232     0.459    27.565
 H-2S
INCREMENT!      0.002      0.002       0.000    73.693     0.074     0.075     0.044     0.015    -0.002    39.304     0.074     2.467
TOTAL AMB!      0.002      0.002       0.000    73.694     0.074     0.075     3.027     1.017     0.036    52.288     0.211    60.379
 0
INCREMENT!      0.001      0.000       0.000     0.000     3.545     0.021     0.504     0.598    -0.000    11.249     0.042    50.529
TOTAL AMB!      0.001      0.000       0.000    71.679     3.545     0.021     3.488     3.993     0.038    24.233     0.178    82.209


CUMULATIVE SURFACE DEPOSITION (MOLE FRACTION OF INITIAL FLUX)
                    SO2!   0.0000
                    NOX!   0.0000
PRIMARY PARTICULATE!   0.0000
                    SO4!   0.0000
                    NO3!   0.0000
1
                 VISUAL EFFECTS FOR HORIZONTAL SIGHT PATHS
                 VISTTA 81 - CASE 8
DOWNWIND DISTANCE (KM) =    10.0
PLUME ALTITUDE (M)     =    382.
PLUME-OBSERVER DISTANCE (KM) =     9.3
AZIMUTH OF LINE-OF-SIGHT =  191.6
ELEVATION ANGLE OF LINE-OF-SIGHT =     3.7
ELEVATION ANGLE OF LINE-OF-SIGHT =    3.7


1                                                                                                       PAGE    8


SOLAR ZENITH ANGLE =   55.6   AT  850.  ON  9/ 8
SIGHT PATH IS THROUGH PLUME CENTER
THETA ALPHA  RP/RVO     RV  %REDUCED     YCAP         L         X         Y DELYCAP     DELL  C(550)  BRATIO    DELX     DELY  E(LUV)  E(LAB)

  83.
       53.     0. 05   170. 0     1. 76    49. 52    75. 79  0. 3097  0. 3261    -1. 51    -0. 92 -0. 0291  0. 9940  0. 0006  0. 0006  1. 0693  0. 975
1
       PLUME VISUAL EFFECTS FOR HORIZONTAL VIEWS
       OF THE PLUME OF WHITE, GRAY, AND BLACK OBJECTS
       FOR SPECIFIC OBSERVER-PLUME AND OBSERVER-OBJECT DISTANCES

       VISTTA 81 - CASE 8

DOWNWIND DISTANCE (KM) =    10. 0
PLUME-OBSERVER DISTANCE (KM) =     9. 3
AZIMUTH OF LINE-OF-SIGHT =  191. 6
ELEVATION ANGLE OF LINE-OF-SIGHT =     3. 7
SOLAR ZENITH ANGLE =   55. 6   AT  850.  ON  9/ 8
THETA =   83.

REFLECT  RP/RVO  RO/RVO     YCAP        L        X        Y DELYCAP     DELL  C(550)  BRATIO     DELX     DELY  E(LUV)  E(LAB)
    1. 0    0. 05     3. 47    19. 71    51. 55  0. 3386  0. 3482  -31. 57  -25 32 -0. 6233  0. 4609  0. 0350  0. 0293 32. 7245 28. 5088
    0. 3    0. 05     3. 47    19. 71    51. 54  0. 3386  0. 3482  -31. 57  -25. 32 -0. 6233  0. 4613  0. 0350  0. 0293 32. 7236 28. 5086
    0. 0    0. 05     3. 47    19. 71    51. 54  0. 3386  0. 3482  -31. 57  -25. 32 -0. 6233  0. 4615  0. 0350  0. 0293 32. 7231 28. 5086
1
                    CONCENTRATIONS OF AEROSOL AND GASES CONTRIBUTED BY

                               VISTTA 81 - CASE 8
DOWNWIND DISTANCE (KM) =    15. 0
PLUME ALTITUDE (M)     =    382.
SIGMA Y (M)            =    790.
SIGMA Z (M)            =    171.
SO2-SO4 CONVERSION RATE=        0. 0263 PERCENT/HR
NOX-NO3 CONVERSION RATE=        0. 1844 PERCENT/HR

ALTITUDE            NOX         NO2         NO3-  NO2/NTOT  NO3-/NTOT       SO2      SO4=  SO4=/STOT       O3     PRIMARY BSP-TOTAL  BSPSN/BS
                  (PPM)       (PPM)        (PPM)  (MOLE %)  (MOLE %)      (PPM)   (UG/M3)  (MOLE %)      (PPM)    (UG/M3) (10-4 M-1)   (%)
 H+2S
INCREMENT!      0. 001      0. 001      0. 000     73. 865     0. 277     0. 041     0. 088     0. 054    -0. 001     21. 582     0. 043     8. 484
TOTAL AMB!      0. 001      0. 001      0. 000     73. 900     0. 277     0. 041     3. 071     1. 864     0. 037     34. 565     0. 180    71. 764
 H+1S
INCREMENT!      0. 005      0. 004      0. 000     72. 486     0. 046     0. 185     0. 071     0. 010    -0. 004     96. 723     0. 181     1. 638
TOTAL AMB!      0. 005      0. 004      0. 000     72. 520     0. 046     0. 185     3. 054     0. 419     0. 034    109. 707     0. 318    40. 392
 H
INCREMENT!      0. 008      0. 006      0. 000     71. 125     0. 022     0. 305     0. 060     0. 005    -0. 006    159. 477     0. 297     0. 848
TOTAL AMB!      0. 008      0. 006      0. 000     71. 158     0. 022     0. 305     3. 043     0. 254     0. 032    172. 461     0. 433    29. 532
 H-1S
INCREMENT!      0. 005      0. 004      0. 000     72. 477     0. 046     0. 185     0. 071     0. 010    -0. 004     97. 116     0. 182     1. 638
TOTAL AMB!      0. 005      0. 004      0. 000     72. 512     0. 046     0. 185     3. 054     0. 418     0. 034    110. 099     0. 318    40. 303
 H-2S
INCREMENT!      0. 002      0. 001      0. 000     73. 716     0. 275     0. 056     0. 118     0. 054    -0. 001     29. 203     0. 059     8. 418
TOTAL AMB!      0. 002      0. 001      0. 000     73. 750     0. 275     0. 056     3. 101     1. 397     0. 037     42. 186     0. 195    66. 777
  0
INCREMENT!      0. 001      0. 001      0. 000     71. 046     3 974      0. 050     1. 364     0. 690    -0. 001     26. 356     0. 106    54. 101
TOTAL AMB!      0. 001      0. 001      0. 000     71. 079     3 976      0. 050     4. 347     2. 167     0. 037     39. 339     0. 242    75. 404
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1                                                                                                        PAGE    9


     CUMULATIVE SURFACE DEPOSITION (MOLE FRACTION OF INITIAL FLUX)
                    SO2!    0.0005
                    NOX!    0.0005
     PRIMARY PARTICULATE!   0.0000
                    SO4!    0.0000
                    NO3!    0.0000
1
                     VISUAL EFFECTS FOR HORIZONTAL SIGHT PATHS
                     VISTTA 81 - CASE 8
     DOWNWIND DISTANCE (KM) =    15.0
     PLUME ALTITUDE (M)      =    382.
     PLUME-OBSERVER DISTANCE (KM) =     7.4
     AZIMUTH OF LINE-OF-SIGHT =  224.2
     ELEVATION ANGLE OF LINE-OF-SIGHT =     4.6
     SOLAR ZENITH ANGLE =    55.6   AT  850.  ON   9/ 8
     SIGHT PATH IS THROUGH PLUME CENTER
     THETA ALPHA  RP/RVO     RV  %REDUCED     YCAP        L        X         Y DELYCAP     DELL  C(550)  BRATIO    DELX     DELY  E(LUV)  E(LAB)

      109.
             85.     0.04    171.2    1.04    43.88    72.17  0.3035  0.3199    -1.01    -0.67 -0.0225  0.9941  0.0005  0.0004  0.8122  0.722
1
             PLUME VISUAL EFFECTS FOR HORIZONTAL VIEWS
             OF THE PLUME OF WHITE, GRAY, AND BLACK OBJECTS
             FOR SPECIFIC OBSERVER-PLUME AND OBSERVER-OBJECT DISTANCES

             VISTTA 81 - CASE 8

     DOWNWIND DISTANCE (KM) =    15.0
     PLUME-OBSERVER DISTANCE (KM) =     7.4
     AZIMUTH OF LINE-OF-SIGHT =  224.2
     ELEVATION ANGLE OF LINE-OF-SIGHT =     4.6
     SOLAR ZENITH ANGLE =    55.6    AT   850.  ON   9/ 8
     THETA =  109.

     REFLECT  RP/RVO   RO/RVO    YCAP       L       X        Y DELYCAP     DELL  C(550)   BRATIO    DELX     DELY  E(LUV)  E(LAB)
        1.0    0.04     3.47    16.20    47.27  0.3279  0.3394   -28.13   -25.20 -0.6401  0.4820  0.0330  0.0291 33.0209 28.4339
        0.3    0.04     3.47    16.20    47.27  0.3279  0.3394   -28.13   -25.20 -0.6401  0.4828  0.0330  0.0291 33.0198 28.4338
        0.0    0.04     3.47    16.20    47.27  0.3279  0.3394   -28.13   -25.20 -0.6401  0.4831  0.0330  0.0291 33.0193 28.4337
1
                        CONCENTRATIONS OF AEROSOL AND GASES CONTRIBUTED BY

                                        VISTTA 81 - CASE 8
     DOWNWIND DISTANCE (KM) =    20.4
     PLUME ALTITUDE (M)     =    382.
     SIGMA Y (M)            =   1035.
     SIGMA Z (M)            =    202.
     SO2-SO4 CONVERSION RATE=         0.0546 PERCENT/HR
     NOX-NO3 CONVERSION RATE=         0.3819 PERCENT/HR

     ALTITUDE          NOX        NO2         NO3-  NO2/NTOT  NO3-/NTOT      SO2       SO4=  SO4=/STOT      O3      PRIMARY BSP-TOTAL  BSPSN/BS
                      (PPM)      (PPM)       (PPM)  (MOLE %)  (MOLE %)      (PPM)    (UG/M3)  (MOLE %)    (PPM)    (UG/M3) (10-4 M-1)   (%)
      H+2S
     INCREMENT!       0.001      0.001       0.000    73.604     0.666      0.027     0.136     0.130    -0.001     13.918     0.031    18.181
     TOTAL AMB!       0.001      0.001       0.000    73.763     0.667      0.027     3.119     2.911     0.037     26.901     0.168    78.153
      H+1S
     INCREMENT!       0.003      0.002       0.000    73.033     0.121      0.119     0.119     0.025    -0.002     62.376     0.120     4.167
     TOTAL AMB!       0.003      0.002       0.000    73.190     0.121      0.119     3.102     0.660     0.036     75.360     0.256    50.846
```

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 TOTAL AMB!    0.002    0.002    0.000

1
                                                                                  PAGE   10

 H
 INCREMENT!    0.005    0.004    0.000   72.224    0.061    0.196    0.107    0.014   -0.004  102.922    0.194    2.323
 TOTAL AMB!    0.005    0.004    0.000   72.381    0.061    0.196    3.091    0.400    0.034  115.905    0.331   39.274
  H-1S
 INCREMENT!    0.003    0.003    0.000   72.988    0.120    0.123    0.123    0.025   -0.002   64.552    0.124    4.155
 TOTAL AMB!    0.003    0.003    0.000   73.146    0.120    0.123    3.106    0.639    0.036   77.536    0.261   50.093
  H-2S
 INCREMENT!    0.002    0.001    0.000   73.282    0.551    0.066    0.280    0.108   -0.001   34.581    0.076   15.589
 TOTAL AMB!    0.002    0.001    0.000   73.440    0.552    0.066    3.264    1.246    0.037   47.565    0.212   64.721
  O
 INCREMENT!    0.002    0.001    0.000   70.799    3.932    0.065    1.789    0.689   -0.001   34.581    0.139   54.089
 TOTAL AMB!    0.002    0.001    0.000   70.952    3.941    0.065    4.772    1.822    0.037   47.565    0.275   72.843


 CUMULATIVE SURFACE DEPOSITION (MOLE FRACTION OF INITIAL FLUX)
               SO2!     0.0021
               NOX!     0.0021
 PRIMARY PARTICULATE!   0.0002
               SO4!     0.0000
               NO3!     0.0000
1
               VISUAL EFFECTS FOR HORIZONTAL SIGHT PATHS
               VISTTA 81 - CASE 8
 DOWNWIND DISTANCE (KM) =   20.4
 PLUME ALTITUDE (M)     =   382.
 PLUME-OBSERVER DISTANCE (KM) =     8.8
 AZIMUTH OF LINE-OF-SIGHT =  262.1
 ELEVATION ANGLE OF LINE-OF-SIGHT =     3.9
 SOLAR ZENITH ANGLE =    55.6   AT  850.  ON   9/ 8
 SIGHT PATH IS THROUGH PLUME CENTER
 THETA ALPHA  RP/RVO    RV  %REDUCED    YCAP        L        X        Y DELYCAP    DELL  C(550)  BRATIO    DELX    DELY  E(LUV)  E(LAB)
  135.
         57.    0.05   171.2    1.04   45.62   73.32  0.3030  0.3190   -1.19   -0.77 -0.0250  0.9971  0.0004  0.0004  0.8850  0.808
1
         PLUME VISUAL EFFECTS FOR HORIZONTAL VIEWS
         OF THE PLUME OF WHITE, GRAY, AND BLACK OBJECTS
         FOR SPECIFIC OBSERVER-PLUME AND OBSERVER-OBJECT DISTANCES

         VISTTA 81 - CASE 8

 DOWNWIND DISTANCE (KM) =   20.4
 PLUME-OBSERVER DISTANCE (KM) =     8.8
 AZIMUTH OF LINE-OF-SIGHT =  262.1
 ELEVATION ANGLE OF LINE-OF-SIGHT =     3.9
 SOLAR ZENITH ANGLE =    55.6   AT  850.  ON   9/ 8
 THETA =  135.

 REFLECT  RP/RVO  RO/RVO    YCAP       L       X        Y DELYCAP    DELL  C(550)  BRATIO    DELX    DELY  E(LUV)  E(LAB)
    1.0    0.05    3.47   19.27   51.03  0.3226  0.3349  -26.52  -22.39 -0.5842  0.5544  0.0268  0.0242 29.2567 25.1615
    0.3    0.05    3.47   19.26   51.03  0.3226  0.3350  -26.52  -22.39 -0.5842  0.5551  0.0268  0.0242 29.2558 25.1614
    0.0    0.05    3.47   19.26   51.03  0.3226  0.3350  -26.52  -22.39 -0.5842  0.5554  0.0268  0.0242 29.2555 25.1614
1
 HISTORY OF PLUME PARCEL AT DOWNWIND DISTANCE =    1.0 KM

    PARCEL     LOCAL      SO2-TO-SO4= CONVERSION RATE (%/HR)      NOX-TO-HNO3 CONVERSION RATE (%/HR)
```

```
1                                                                                                          PAGE   11

     AGE        TIME
     (HR)                       H+2S  H+1S  H     H-1S  H-2S   0            H+2S  H+1S  H     H-1S  H-2S   0
     0.0         849            0.00  0.00  0.00  0.00  0.00  0.00          0.00  0.00  0.00  0.00  0.00  0.00
1
 HISTORY OF PLUME PARCEL AT DOWNWIND DISTANCE =   2.0 KM

    PARCEL      LOCAL           SO2-TO-SO4= CONVERSION RATE (%/HR)          NOX-TO-HNO3 CONVERSION RATE (%/HR)
     AGE         TIME
     (HR)                       H+2S  H+1S  H     H-1S  H-2S   0            H+2S  H+1S  H     H-1S  H-2S   0
     0.0         848            0.00  0.00  0.00  0.00  0.00  0.00          0.00  0.00  0.00  0.00  0.00  0.00
     0.1         849            0.00  0.00  0.00  0.00  0.00  2.12          0.01  0.00  0.00  0.00  0.01 14.84
1
 HISTORY OF PLUME PARCEL AT DOWNWIND DISTANCE =   5.0 KM

    PARCEL      LOCAL           SO2-TO-SO4= CONVERSION RATE (%/HR)          NOX-TO-HNO3 CONVERSION RATE (%/HR)
     AGE         TIME
     (HR)                       H+2S  H+1S  H     H-1S  H-2S   0            H+2S  H+1S  H     H-1S  H-2S   0
     0.0         842            0.00  0.00  0.00  0.00  0.00  0.00          0.00  0.00  0.00  0.00  0.00  0.00
     0.1         844            0.00  0.00  0.00  0.00  0.00  2.08          0.01  0.00  0.00  0.00  0.01 14.58
     0.2         849            0.01  0.00  0.00  0.00  0.01  2.12          0.10  0.01  0.00  0.01  0.10 14.84
1
 HISTORY OF PLUME PARCEL AT DOWNWIND DISTANCE =  10.0 KM

    PARCEL      LOCAL           SO2-TO-SO4= CONVERSION RATE (%/HR)          NOX-TO-HNO3 CONVERSION RATE (%/HR)
     AGE         TIME
     (HR)                       H+2S  H+1S  H     H-1S  H-2S   0            H+2S  H+1S  H     H-1S  H-2S   0
     0.0         832            0.00  0.00  0.00  0.00  0.00  0.00          0.00  0.00  0.00  0.00  0.00  0.00
     0.1         834            0.00  0.00  0.00  0.00  0.00  1.97          0.01  0.00  0.00  0.00  0.01 13.80
     0.2         840            0.01  0.00  0.00  0.00  0.01  2.01          0.09  0.01  0.00  0.01  0.09 14.06
     0.3         849            0.08  0.01  0.01  0.01  0.08  2.12          0.59  0.09  0.04  0.09  0.59 14.84
1
 HISTORY OF PLUME PARCEL AT DOWNWIND DISTANCE =  15.0 KM

    PARCEL      LOCAL           SO2-TO-SO4= CONVERSION RATE (%/HR)          NOX-TO-HNO3 CONVERSION RATE (%/HR)
     AGE         TIME
     (HR)                       H+2S  H+1S  H     H-1S  H-2S   0            H+2S  H+1S  H     H-1S  H-2S   0
     0.0         822            0.00  0.00  0.00  0.00  0.00  0.00          0.00  0.00  0.00  0.00  0.00  0.00
     0.1         824            0.00  0.00  0.00  0.00  0.00  1.79          0.01  0.00  0.00  0.00  0.01 12.50
     0.2         830            0.01  0.00  0.00  0.00  0.01  1.82          0.08  0.00  0.00  0.00  0.08 12.76
     0.3         840            0.08  0.01  0.00  0.01  0.08  1.93          0.53  0.08  0.03  0.08  0.53 13.54
     0.5         849            0.25  0.05  0.03  0.05  0.25  0.91          1.77  0.34  0.18  0.34  1.75  6.37
1
 HISTORY OF PLUME PARCEL AT DOWNWIND DISTANCE =  20.4 KM

    PARCEL      LOCAL           SO2-TO-SO4= CONVERSION RATE (%/HR)          NOX-TO-HNO3 CONVERSION RATE (%/HR)
     AGE         TIME
     (HR)                       H+2S  H+1S  H     H-1S  H-2S   0            H+2S  H+1S  H     H-1S  H-2S   0
     0.0         812            0.00  0.00  0.00  0.00  0.00  0.00          0.00  0.00  0.00  0.00  0.00  0.00
     0.1         814            0.00  0.00  0.00  0.00  0.00  1.60          0.01  0.00  0.00  0.00  0.01 11.20
     0.2         820            0.01  0.00  0.00  0.00  0.01  1.64          0.07  0.00  0.00  0.00  0.07 11.46
     0.3         829            0.07  0.01  0.00  0.01  0.07  1.75          0.48  0.07  0.03  0.07  0.48 12.24
     0.5         839            0.23  0.04  0.02  0.04  0.23  0.83          1.62  0.31  0.17  0.31  1.60  5.80
     0.7         849            0.47  0.10  0.05  0.10  0.34  0.38          3.26  0.67  0.38  0.67  2.39  2.68
1                                                                  PLOT FILE VERIFICATION
0                                                                   OBSERVER-BASED DATA
0    SKY BACKGROUND
0        NX                   1      2      3      4      5      6
0   DISTANCE (KM)             1      2      5     10     15     20
```

```
0   DISTANCE (KM)          1       2       5       10      15      20

1

0 REDUCTION OF VISUAL
        RANGE (%)        14.931   8.424   3.733   1.758   1.042   1.041
0   BLUE-RED RATIO
                          1.109   1.059   1.003   0.994   0.994   0.997
0   PLUME CONTRAST AT
         0.55 MICRONS    -0.132  -0.095  -0.056  -0.029  -0.023  -0.025
OPLUME PERCEPTIBILITY
      DELTA E(L*A*B*)     5.626   3.415   1.867   0.976   0.722   0.808

0    WHITE BACKGROUND
0          NX               1       2       3       4       5       6
0    DISTANCE (KM)          1       2       5      10      15      20
0 REDUCTION OF VISUAL
        RANGE (%)         0.000   0.000   0.000   0.000   0.000   0.000
0   BLUE-RED RATIO
                          0.680   0.561   0.524   0.461   0.482   0.554
0   PLUME CONTRAST AT
         0.55 MICRONS    -0.525  -0.512  -0.571  -0.623  -0.640  -0.584
OPLUME PERCEPTIBILITY
      DELTA E(L*A*B*)    22.634  23.493  25.776  28.509  28.434  25.162

0     GRAY BACKGROUND
0          NX               1       2       3       4       5       6
0    DISTANCE (KM)          1       2       5      10      15      20
0 REDUCTION OF VISUAL
        RANGE (%)         0.000   0.000   0.000   0.000   0.000   0.000
0   BLUE-RED RATIO
                          0.680   0.561   0.524   0.461   0.483   0.555
0   PLUME CONTRAST AT
         0.55 MICRONS    -0.525  -0.512  -0.571  -0.623  -0.640  -0.584
OPLUME PERCEPTIBILITY
      DELTA E(L*A*B*)    22.634  23.493  25.776  28.509  28.434  25.161
1    BLACK BACKGROUND
0          NX               1       2       3       4       5       6
0    DISTANCE (KM)          1       2       5      10      15      20
0 REDUCTION OF VISUAL
        RANGE (%)         0.000   0.000   0.000   0.000   0.000   0.000
0   BLUE-RED RATIO
                          0.680   0.561   0.524   0.462   0.483   0.555
0   PLUME CONTRAST AT
         0.55 MICRONS    -0.525  -0.512  -0.571  -0.623  -0.640  -0.584
OPLUME PERCEPTIBILITY
      DELTA E(L*A*B*)    22.634  23.493  25.776  28.509  28.434  25.161
```

APPENDIX B

SAMPLE PLUVUE II SIMULATION
(PLUME-BASED)

INPUT DATA FILE

```
VISTTA DEC  7 3-94                                                                      PAGE   1


VISTTA DEC. 7 3-94
  4. 5    5-1. 48
000517
0 0        0. 0
10000. 0
60.
    0
 1 0 0 0 2 3 3 1
 1
1. 0        2. 0
    146. 00      110. 00      6. 40
 3160000. 0      300. 0       3. 0       27. 0
  3. 0775 0
      42. 0
     0. 000      0. 000      0. 034      0. 000
     0. 125      3. 000      0. 125      2. 500
     1. 600      1. 300      1. 600      2. 000
     1. 800      2. 000      1. 800      2. 000
     0. 030      2. 000      2. 000      0. 000      0. 435
     1. 500      0. 000      1. 500      0. 000
     1. 500      0. 000      2 000       1. 000
     3. 640
   2
   260. 0
1. 00 1. 00 0 10 0. 10
    0
0. 0
   1    1
3 4 3 3 2 1
   464. 8     4084. 0     4360. 0
  12    12   070929.    7.  1979
```

OUTPUT DATA FILE

```
1                                                                                    PAGE    1

1
VISUAL IMPACT ASSESSMENT FOR VISTTA DEC. 7 3-94
    EMISSIONS SOURCE DATA

        ELEVATION OF SITE =      4360   FEET MSL
                                 1329.  METERS MSL
        NO. OF UNITS =     3.
        STACK HEIGHT =  775.  FEET
                        236.  METERS
        FLUE GAS FLOW RATE =   3160000.  CU FT/MIN
                               1491.14  CU M/SEC
        FLUE GAS TEMPERATURE =       300.  F
                                     422.  K
        FLUE GAS OXYGEN CONTENT =        3.0  MOL PERCENT
        SO2 EMISSION RATE (TOTAL) =     146.00  TONS/DAY
                                      1.533E 03  G/SEC
        NOX EMISSION RATE (TOTAL,AS NO2) =     110.00  TONS/DAY
                                             1.155E 03  G/SEC
        PARTICULATE EMISSION RATE (TOTAL) =       6.40  TONS/DAY
                                               6.720E 01  G/SEC
1


    METEOROLOGICAL AND AMBIENT AIR QUALITY DATA

        WINDSPEED =   4.5  MILES/HR
                      2.0  M/SEC

        PASQUILL-GIFFORD-TURNER STABILITY CATEGORY E

        LAPSE RATE = -1.48  F/1000 FT
                    -2.698E-03  K/M
        POTENTIAL TEMPERATURE LAPSE RATE =    7.102E-03  K/M
        AMBIENT TEMPERATURE =  42.0  F
                              278.7  K
        RELATIVE HUMIDITY =  60.0  %
        MIXING DEPTH = $1000  M
        AMBIENT PRESSURE =  0.86  ATM

        BACKGROUND NOX CONCENTRATION =      0.000  PPM

        BACKGROUND NO2 CONCENTRATION =      0.000  PPM

        BACKGROUND OZONE CONCENTRATION =      0.034  PPM

        BACKGROUND SO2 CONCENTRATION =      0.000  PPM


        BACKGROUND COARSE MODE CONCENTRATION =        3.6  UG/M3
        BACKGROUND SULFATE CONCENTRATION =        0.5  UG/M3
        BACKGROUND NITRATE CONCENTRATION =        0.0  UG/M3
        BACKGROUND VISUAL RANGE =      260.0  KILOMETERS
        SO2 DEPOSITION VELOCITY =       1.00  CM/SEC
        NOX DEPOSITION VELOCITY =       1.00  CM/SEC
        COARSE PARTICULATE DEPOSITION VELOCITY =       0.10  CM/SEC
```

```
1                                                                                                    PAGE    2

          SUBMICRON PARTICULATE DEPOSITION VELOCITY =        0.10  CM/SEC

                                      AEROSOL STATISTICS

                                    BACKGROUND                                      PLUME

          MASS MEDIAN     ACCUMULATION         COARSE          ACCUMULATION         COARSE          CARBONACEOUS
          RADIUS              MODE              MODE               MODE              MODE               AEROSOLS
          MICROMETERS        0.125             3.000              0.125             2.500              0.050

          GEOMETRIC
          STANDARD
          DEVIATION          1.600             1.300              1.600             2.000              2.000

          PARTICLE
          DENSITY
          G/(CM**3)          1.800             2.000              1.800             2.000              2.000
 CARBONACEOUS FRACTION OF PARTICULATE MASS EMISSIONS =       0.000
 BACKGROUND ATMOSPHERIC ELEMENTAL CARBON =       0.435 UG/M**3

          SIMULATION IS FOR  929. HOURS ON 12/ 7
          SOLAR ZENITH ANGLE (DEGREES) = 71.6
          SOLAR AZIMUTH ANGLE (DEGREES) =   139.2

1                                 BACKGROUND CONDITIONS

   ACCUMULATION MODE                              COARSE PARTICLE MODE                              PRIMARY PARTICLE MODE
   MASS RADIUS     SIGMA    BSCAT.55/MASS           MASS RADIUS     SIGMA    BSCAT.55/MASS             MASS RADIUS     SIGMA    BSCAT.55/MASS
  0.1250E 00   0.1600E 01    0.4015E-02             0.3000E 01   0.1300E 01    0.2809E-03              0.2500E 01   0.2000E 01    0.4475E-03


                                                REFRACTION INDEXES
   ACCUMULATION MODE        =    0.1500E 01 + I    0.0000E 00
   COARSE MODE              =    0.1500E 01 + I    0.0000E 00
   PRIMARY AEROSOLS         =    0.1500E 01 + I    0.0000E 00
   CARBONACEOUS AEROSOLS    =    0.2000E 01 + I    0.1000E 01

                           COEFFICIENTS AT 0.55 MICROMETERS , 1./KM
    BTARAY =0.1015E-01   BTAAER =0.6379E-02   ABSNO2 =0.0000E 00   BTABAC =0.1505E-01
1
                         INITIAL PLUME RISE AND DILUTION AND NITROGEN DIOXIDE FORMATION

                                          VISTTA DEC.  7 3-94

 TIME       X     DELTA H     U        W        V      SIGMA     TEMP      O2     NO2-NO RATIO      NOX       NO       NO2T      SO2    PARTICULATE
 (SEC)     (M)      (M)     (M/S)    (M/S)    (M/S)     (M)       (K)    MOL P   EQUIL   ACTUAL   (PPM)     (PPM)     (PPM)    (PPM)      UG/M3
   0.      0.0      0.0     2.01    27.00    27.00      0.0     422.0      3.0 1.0E 03 1.7E-03 226.439  226.063     0.376  216.065    2.48E 04
  10.     20.1     51.9     2.01     1.82     2.71     12.1     350.1     12.0 5.2E 04 2.6E-03 112.847  112.553     0.294  107.677    1.24E 04
  20.     40.2     82.4     2.01     1.47     2.49     19.2     305.7     17.6 4.7E 05 5.0E-03  42.597   42.383     0.214   40.645    4.66E 03
  30.     60.3    108.0     2.01     1.29     2.39     25.1     294.5     19.0 8.1E 05 6.7E-03  24.908   24.742     0.166   23.767    2.73E 03
  40.     80.5    130.8     2.01     1.17     2.33     30.4     289.5     19.6 1.0E 06 7.8E-03  17.117   16.984     0.133   16.333    1.87E 03
  50.    100.6    151.8     2.01     1.09     2.29     35.3     286.8     19.9 1.2E 06 8.7E-03  12.815   12.705     0.110   12.228    1.40E 03
```

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 1                                                                                                   PAGE    3

   60.     120.7    171.4     2.01    1.03    2.26    39.9   285.1   20.1 1.3E 06 9.3E-03 10.120 10.027  0.093  9.656  1.11E 03
   70.     140.8    189.9     2.01    0.98    2.24    44.2   284.0   20.3 1.3E 06 9.8E-03  8.289  8.209  0.081  7.910  9.07E 02
   80.     160.9    207.6     2.01    0.94    2.22    48.3   283.1   20.4 1.4E 06 1.0E-02  6.973  6.903  0.071  6.654  7.63E 02
   90.     181.0    224.6     2.01    0.90    2.20    52.2   282.5   20.5 1.4E 06 1.1E-02  5.987  5.924  0.063  5.712  6.55E 02
  100.     201.1    240.9     2.01    0.87    2.19    56.0   282.0   20.5 1.5E 06 1.1E-02  5.222  5.166  0.056  4.983  5.72E 02
  110.     221.3    256.7     2.01    0.84    2.18    59.7   281.6   20.6 1.5E 06 1.1E-02  4.615  4.564  0.051  4.404  5.05E 02
  120.     241.4    272.1     2.01    0.82    2.17    63.3   281.3   20.6 1.5E 06 1.1E-02  4.122  4.076  0.047  3.933  4.51E 02
  130.     261.5    287.0     2.01    0.80    2.16    66.7   281.1   20.7 1.5E 06 1.2E-02  3.715  3.672  0.043  3.545  4.07E 02
  140.     281.6    301.5     2.01    0.78    2.16    70.1   280.8   20.7 1.6E 06 1.2E-02  3.374  3.334  0.040  3.219  3.69E 02
  150.     301.7    315.7     2.01    0.76    2.15    73.4   280.7   20.7 1.6E 06 1.2E-02  3.084  3.048  0.037  2.943  3.38E 02
  160.     321.8    329.6     2.01    0.74    2.14    76.6   280.5   20.7 1.6E 06 1.2E-02  2.836  2.802  0.034  2.706  3.10E 02
  170.     342.0    343.2     2.01    0.73    2.14    79.8   280.4   20.7 1.6E 06 1.2E-02  2.621  2.589  0.032  2.501  2.87E 02
  180.     362.1    356.5     2.01    0.72    2.13    82.9   280.2   20.8 1.6E 06 1.3E-02  2.433  2.403  0.030  2.321  2.66E 02
  190.     382.2    369.6     2.01    0.70    2.13    86.0   280.1   20.8 1.6E 06 1.3E-02  2.267  2.239  0.028  2.163  2.48E 02
  200.     402.3    380.9     2.01    0.69    2.13    88.6   280.1   20.8 1.6E 06 1.3E-02  2.138  2.111  0.027  2.040  2.34E 02
  210.     422.4    380.9     2.01    0.68    2.12    88.6   280.1   20.8 1.6E 06 1.3E-02  2.141  2.114  0.027  2.043  2.34E 02
  220.     442.5    380.9     2.01    0.67    2.12    88.6   280.1   20.8 1.6E 06 1.3E-02  2.145  2.117  0.027  2.046  2.35E 02
  230.     462.6    380.9     2.01    0.66    2.12    88.6   280.1   20.8 1.6E 06 1.3E-02  2.148  2.120  0.028  2.049  2.35E 02
  240.     482.8    380.9     2.01    0.65    2.11    88.6   280.1   20.8 1.6E 06 1.3E-02  2.151  2.123  0.028  2.052  2.35E 02
  250.     502.9    380.9     2.01    0.64    2.11    88.6   280.1   20.8 1.6E 06 1.3E-02  2.153  2.125  0.028  2.055  2.36E 02
  260.     523.0    380.9     2.01    0.63    2.11    88.6   280.1   20.8 1.6E 06 1.3E-02  2.156  2.127  0.029  2.057  2.36E 02
  270.     543.1    380.9     2.01    0.63    2.11    88.6   280.1   20.8 1.6E 06 1.4E-02  2.158  2.129  0.029  2.059  2.36E 02
  280.     563.2    380.9     2.01    0.62    2.10    88.6   280.1   20.8 1.6E 06 1.4E-02  2.161  2.131  0.029  2.062  2.37E 02
  290.     583.3    380.9     2.01    0.61    2.10    88.6   280.1   20.8 1.6E 06 1.4E-02  2.163  2.133  0.029  2.064  2.37E 02
  300.     603.4    380.9     2.01    0.60    2.10    88.6   280.1   20.8 1.6E 06 1.4E-02  2.165  2.135  0.030  2.066  2.37E 02
  310.     623.6    380.9     2.01    0.60    2.10    88.6   280.1   20.8 1.6E 06 1.4E-02  2.167  2.137  0.030  2.068  2.37E 02
  320.     643.7    380.9     2.01    0.59    2.10    88.6   280.1   20.8 1.6E 06 1.4E-02  2.169  2.138  0.030  2.069  2.37E 02
  330.     663.8    380.9     2.01    0.59    2.09    88.6   280.1   20.8 1.6E 06 1.4E-02  2.170  2.140  0.031  2.071  2.38E 02
  340.     683.9    380.9     2.01    0.58    2.09    88.6   280.1   20.8 1.6E 06 1.4E-02  2.172  2.141  0.031  2.073  2.38E 02
  350.     704.0    380.9     2.01    0.57    2.09    88.6   280.1   20.8 1.6E 06 1.4E-02  2.174  2.143  0.031  2.074  2.38E 02
  360.     724.1    380.9     2.01    0.57    2.09    88.6   280.1   20.8 1.6E 06 1.5E-02  2.175  2.144  0.031  2.076  2.38E 02
  370.     744.3    380.9     2.01    0.56    2.09    88.6   280.1   20.8 1.6E 06 1.5E-02  2.177  2.145  0.032  2.077  2.38E 02
  380.     764.4    380.9     2.01    0.56    2.09    88.6   280.1   20.8 1.6E 06 1.5E-02  2.178  2.146  0.032  2.078  2.38E 02
  390.     784.5    380.9     2.01    0.55    2.09    88.6   280.1   20.8 1.6E 06 1.5E-02  2.179  2.147  0.032  2.080  2.39E 02
  400.     804.6    380.9     2.01    0.55    2.09    88.6   280.1   20.8 1.6E 06 1.5E-02  2.181  2.148  0.032  2.081  2.39E 02
  410.     824.7    380.9     2.01    0.54    2.08    88.6   280.1   20.8 1.6E 06 1.5E-02  2.182  2.149  0.033  2.082  2.39E 02
  420.     844.8    380.9     2.01    0.54    2.08    88.6   280.1   20.8 1.6E 06 1.5E-02  2.183  2.150  0.033  2.083  2.39E 02
  430.     864.9    380.9     2.01    0.54    2.08    88.6   280.1   20.8 1.6E 06 1.5E-02  2.184  2.151  0.033  2.084  2.39E 02
  440.     885.1    380.9     2.01    0.53    2.08    88.6   280.1   20.8 1.6E 06 1.6E-02  2.185  2.152  0.033  2.085  2.39E 02
  450.     905.2    380.9     2.01    0.53    2.08    88.6   280.1   20.8 1.6E 06 1.6E-02  2.186  2.153  0.034  2.086  2.39E 02
  460.     925.3    380.9     2.01    0.52    2.08    88.6   280.1   20.8 1.6E 06 1.6E-02  2.187  2.153  0.034  2.087  2.39E 02
  470.     945.4    380.9     2.01    0.52    2.08    88.6   290.1   20.8 1.6E 06 1.6E-02  2.188  2.154  0.034  2.088  2.40E 02
  480.     965.5    380.9     2.01    0.52    2.08    88.6   280.1   20.8 1.6E 06 1.6E-02  2.189  2.155  0.035  2.089  2.40E 02
  490.     985.6    380.9     2.01    0.51    2.08    88.6   280.1   20.8 1.6E 06 1.6E-02  2.190  2.156  0.035  2.090  2.40E 02
 1
                        CONCENTRATIONS OF AEROSOL AND GASES CONTRIBUTED BY

                                     VISTTA DEC. 7 3-94
 DOWNWIND DISTANCE (KM) =     1.0
 PLUME ALTITUDE (M)     =   617.
 SIGMA Y (M)            =   146.
 SIGMA Z (M)            =    44.
 SO2-SO4 CONVERSION RATE=       0.0000 PERCENT/HR
 NOX-NO3 CONVERSION RATE=       0.0000 PERCENT/HR

 ALTITUDE          NOX      NO2       NO3-  NO2/NTOT  NO3-/NTOT     SO2       SO4=  SO4=/STOT     O3     PRIMARY BSP-TOTAL  BSPSN/BS
                  (PPM)    (PPM)     (PPM)  (MOLE %)  (MOLE %)     (PPM)   (UG/M3)  (MOLE %)    (PPM)   (UG/M3) (10-4 M-1)    (%)
  H+2S
```

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1                                                                                                        PAGE    4

 INCREMENT!    1.110     0.051     0.000      4.623     0.000      1.060     0.000      0.000    -0.034   121.556     0.544     0.000
 TOTAL AMB!    1.110     0.051     0.000      4.623     0.000      1.060     0.497      0.012     0.000   125.694     0.608     3.285
  H+1S
 INCREMENT!    4.977     0.113     0.000      2.279     0.000      4.749     0.000      0.000    -0.034   544.778     2.438     0.000
 TOTAL AMB!    4.977     0.113     0.000      2.279     0.000      4.749     0.497      0.003     0.000   548.915     2.502     0.798
  H
 INCREMENT!    8.205     0.165     0.000      2.012     0.000      7.829     0.000      0.000    -0.034   898.186     4.019     0.000
 TOTAL AMB!    8.205     0.165     0.000      2.012     0.000      7.829     0.497      0.002     0.000   902.323     4.083     0.489
  H-1S
 INCREMENT!    4.977     0.113     0.000      2.279     0.000      4.749     0.000      0.000    -0.034   544.777     2.438     0.000
 TOTAL AMB!    4.977     0.113     0.000      2.279     0.000      4.749     0.497      0.003     0.000   548.914     2.502     0.798
  H-2S
 INCREMENT!    1.110     0.051     0.000      4.623     0.000      1.060     0.000      0.000    -0.034   121.556     0.544     0.000
 TOTAL AMB!    1.110     0.051     0.000      4.623     0.000      1.060     0.497      0.012     0.000   125.693     0.608     3.285
  O
 INCREMENT!    0.000     0.000     0.000      0.000     0.000      0.000     0.000      0.000     0.000     0.000     0.000     0.000
 TOTAL AMB!    0.000     0.000     0.000    100.000     0.000      0.000     0.497    100.000     0.034     4.137     0.064    31.298


 CUMULATIVE SURFACE DEPOSITION (MOLE FRACTION OF INITIAL FLUX)
                   SO2!    0.0000
                   NOX!    0.0000
 PRIMARY PARTICULATE!    0.0000
                   SO4!    0.0000
                   NO3!    0.0000
1
                 VISUAL EFFECTS FOR HORIZONTAL SIGHT PATHS
                 VISTTA DEC. 7 3-94
 DOWNWIND DISTANCE (KM) =     1.0
 PLUME ALTITUDE (M)     =   617.
 SIGHT PATH IS THROUGH PLUME CENTER
 THETA ALPHA  RP/RVO    RV  %REDUCED    YCAP      L       X        Y DELYCAP    DELL  C(550)  BRATIO    DELX    DELY  E(LUV)  E(LAB)

  90.
          30.   0.02   247.3    4.89   34.86   65.67  0.3187  0.3425   -5.89   -4.36 -0.1394  0.8655  0.0083  0.0090  7.6133  6.021
          30.   0.05   246.2    5.32   35.51   66.17  0.3158  0.3388   -5.24   -3.85 -0.1245  0.9250  0.0054  0.0053  5.6739  4.691
          30.   0.10   244.6    5.94   36.44   66.88  0.3125  0.3349   -4.31   -3.14 -0.1032  0.9853  0.0022  0.0015  3.6697  3.337
          30.   0.20   242.2    6.83   37.80   67.90  0.3095  0.3317   -2.95   -2.13 -0.0713  1.0301 -0.0009 -0.0018  2.2484  2.211
          30.   0.50   239.0    8.07   39.71   69.29  0.3089  0.3316   -1.03   -0.73 -0.0253  1.0210 -0.0015 -0.0018  1.2302  1.017
          30.   0.80   238.1    8.44   40.31   69.72  0.3099  0.3326   -0.44   -0.31 -0.0111  1.0016 -0.0005 -0.0008  0.5193  0.440
          45.   0.02   251.2    3.38   36.37   66.83  0.3165  0.3402   -4.38   -3.19 -0.1033  0.8980  0.0061  0.0067  5.6881  4.467
          45.   0.05   250.4    3.69   36.86   67.20  0.3144  0.3376   -3.89   -2.83 -0.0923  0.9421  0.0040  0.0041  4.2535  3.488
          45.   0.10   249.3    4.13   37.55   67.71  0.3121  0.3347   -3.20   -2.31 -0.0765  0.9872  0.0017  0.0012  2.7463  2.474
          45.   0.20   247.6    4.78   38.56   68.46  0.3098  0.3322   -2.19   -1.57 -0.0529  1.0211 -0.0005 -0.0012  1.6469  1.622
          45.   0.50   245.2    5.68   39.98   69.48  0.3093  0.3321   -0.77   -0.54 -0.0188  1.0154 -0.0011 -0.0013  0.9021  0.748
          45.   0.80   244.5    5.96   40.43   69.80  0.3100  0.3329   -0.32   -0.23 -0.0082  1.0012 -0.0004 -0.0006  0.3820  0.324
          60.   0.02   252.9    2.73   37.10   67.38  0.3155  0.3391   -3.65   -2.65 -0.0862  0.9141  0.0051  0.0056  4.7591  3.725
          60.   0.05   252.2    2.99   37.50   67.68  0.3138  0.3369   -3.25   -2.34 -0.0770  0.9509  0.0034  0.0035  3.5647  2.912
          60.   0.10   251.3    3.35   38.08   68.10  0.3118  0.3345   -2.67   -1.92 -0.0638  0.9886  0.0015  0.0011  2.3005  2.064
          60.   0.20   249.9    3.88   38.92   68.72  0.3100  0.3325   -1.83   -1.30 -0.0441  1.0171 -0.0004 -0.0010  1.3664  1.346
          60.   0.50   248.0    4.63   40.11   69.57  0.3095  0.3324   -0.64   -0.45 -0.0157  1.0128 -0.0009 -0.0011  0.7486  0.622
          60.   0.80   247.4    4.86   40.48   69.84  0.3101  0.3330   -0.27   -0.19 -0.0069  1.0010 -0.0003 -0.0005  0.3176  0.270
          90.   0.02   253.9    2.35   37.54   67.71  0.3148  0.3384   -3.21   -2.32 -0.0756  0.9242  0.0044  0.0049  4.1820  3.267
          90.   0.05   253.3    2.57   37.90   67.97  0.3134  0.3365   -2.85   -2.05 -0.0675  0.9565  0.0030  0.0030  3.1356  2.556
          90.   0.10   252.5    2.89   38.40   68.34  0.3117  0.3344   -2.34   -1.68 -0.0560  0.9896  0.0013  0.0010  2.0233  1.810
          90.   0.20   251.3    3.35   39.15   68.88  0.3100  0.3326   -1.60   -1.14 -0.0387  1.0148 -0.0004 -0.0008  1.1948  1.178
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1                                                                                                            PAGE    5

          90.     0.50   249.6    4.01   40.19   69.63  0.3096  0.3325   -0.56   -0.40 -0.0137  1.0112 -0.0008 -0.0010  0.6546  0.544
          90.     0.80   249.1    4.21   40.51   69.86  0.3101  0.3330   -0.24   -0.17 -0.0060  1.0008 -0.0003 -0.0004  0.2779  0.236
0    OBSERVER POSITION AT 1/2 OF A 22.5 DEGREE WIND DIRECTION SECTOR FROM THE PLUME CENTERLINE AT THE GIVEN DISTANCE FROM THE SOURCE
          90.     0.02   253.9    2.35   37.53   67.70  0.3149  0.3385   -3.22   -2.32 -0.0758  0.9232  0.0045  0.0050  4.2135  3.289
1
                         CONCENTRATIONS OF AEROSOL AND GASES CONTRIBUTED BY

                                    VISTTA DEC. 7 3-94
DOWNWIND DISTANCE (KM) =    2.0
PLUME ALTITUDE (M)     =   617.
SIGMA Y (M)            =   188.
SIGMA Z (M)            =    51.
SO2-SO4 CONVERSION RATE=      0.0000 PERCENT/HR
NOX-NO3 CONVERSION RATE=      0.0000 PERCENT/HR

ALTITUDE           NOX        NO2         NO3-  NO2/NTOT  NO3-/NTOT       SO2       SO4=   SO4=/STOT       O3      PRIMARY BSP-TOTAL   BSPSN/BS
                  (PPM)      (PPM)        (PPM)  (MOLE %)  (MOLE %)      (PPM)    (UG/M3)  (MOLE %)       (PPM)    (UG/M3) (10-4 M-1)    (%)
  H+2S
INCREMENT!       0.741      0.047       0.000     6.389     0.000      0.707      0.000      0.000     -0.033     81.108      0.363      0.001
TOTAL AMB!       0.741      0.047       0.000     6.389     0.000      0.707      0.497      0.018      0.001     85.246      0.427      4.679
  H+1S
INCREMENT!       3.321      0.129       0.000     3.898     0.000      3.169      0.000      0.000     -0.034    363.503      1.627      0.000
TOTAL AMB!       3.321      0.129       0.000     3.898     0.000      3.169      0.497      0.004      0.000    367.640      1.690      1.181
  H
INCREMENT!       5.475      0.236       0.000     4.320     0.000      5.224      0.000      0.000     -0.034    599.314      2.682      0.000
TOTAL AMB!       5.475      0.236       0.000     4.320     0.000      5.224      0.497      0.002      0.000    603.451      2.746      0.727
  H-1S
INCREMENT!       3.321      0.129       0.000     3.898     0.000      3.169      0.000      0.000     -0.034    363.502      1.627      0.000
TOTAL AMB!       3.321      0.129       0.000     3.898     0.000      3.169      0.497      0.004      0.000    367.639      1.690      1.181
  H-2S
INCREMENT!       0.741      0.047       0.000     6.389     0.000      0.707      0.000      0.000     -0.033     81.108      0.363      0.001
TOTAL AMB!       0.741      0.047       0.000     6.389     0.000      0.707      0.497      0.018      0.001     85.246      0.427      4.679
  0
INCREMENT!       0.000      0.000       0.000     0.000     0.508      0.000      0.000      0.073      0.000      0.000      0.000     18.215
TOTAL AMB!       0.000      0.000       0.000    99.492     0.508      0.000      0.497    100.000      0.034      4.137      0.064     31.298


CUMULATIVE SURFACE DEPOSITION (MOLE FRACTION OF INITIAL FLUX)
                  SO2!    0.0000
                  NOX!    0.0000
PRIMARY PARTICULATE!    0.0000
                  SO4!    0.0000
                  NO3!    0.0000
1
                    VISUAL EFFECTS FOR HORIZONTAL SIGHT PATHS
                    VISTTA DEC. 7 3-94
DOWNWIND DISTANCE (KM) =     2.0
PLUME ALTITUDE (M)     =    617.
SIGHT PATH IS THROUGH PLUME CENTER
THETA ALPHA  RP/RVO     RV  %REDUCED     YCAP        L        X          Y DELYCAP     DELL  C(550)  BRATIO     DELX     DELY  E(LUV)  E(LAB)

  90.
          30.     0.02   248.9     4.26    34.60    65.47  0.3244  0.3487    -6.15    -4.56 -0.1447  0.7879  0.0140  0.0152 10.9047   8.132
          30.     0.05   247.7     4.72    35.30    66.01  0.3203  0.3434    -5.45    -4.02 -0.1291  0.8667  0.0099  0.0100  8.1160   6.149
          30.     0.10   246.1     5.36    36.28    66.76  0.3157  0.3378    -4.47    -3.27 -0.1070  0.9483  0.0053  0.0043  5.0515   4.057
          30.     0.20   243.6     6.30    37.71    67.83  0.3112  0.3329    -3.04    -2.19 -0.0738  1.0136  0.0008 -0.0006  2.4135   2.283
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1                                                                                                    PAGE    6

         30.     0.50   240.3     7.59    39.70    69.28  0.3092  0.3317    -1.05    -0.74 -0.0260  1.0182 -0.0012 -0.0017  1.1393  0.985
         30.     0.80   239.3     7.97    40.31    69.72  0.3100  0.3327    -0.43    -0.31 -0.0112  1.0014 -0.0004 -0.0008  0.4944  0.429
         45.     0.02   252.3     2.95    36.19    66.69  0.3207  0.3448    -4.56    -3.33 -0.1070  0.8375  0.0103  0.0114  8.2015  6.067
         45.     0.05   251.5     3.27    36.71    67.08  0.3178  0.3411    -4.04    -2.94 -0.0955  0.8967  0.0074  0.0076  6.1392  4.613
         45.     0.10   250.3     3.73    37.43    67.63  0.3145  0.3369    -3.32    -2.40 -0.0792  0.9584  0.0041  0.0035  3.8380  3.046
         45.     0.20   248.6     4.40    38.50    68.41  0.3111  0.3332    -2.25    -1.61 -0.0546  1.0084  0.0007 -0.0003  1.7979  1.684
         45.     0.50   246.1     5.34    39.98    69.48  0.3096  0.3322    -0.77    -0.55 -0.0192  1.0132 -0.0008 -0.0012  0.8291  0.721
         45.     0.80   245.4     5.63    40.43    69.80  0.3101  0.3329    -0.32    -0.23 -0.0083  1.0010 -0.0003 -0.0006  0.3615  0.315
         60.     0.02   253.8     2.38    36.94    67.26  0.3189  0.3430    -3.81    -2.76 -0.0892  0.8624  0.0086  0.0095  6.8824  5.072
         60.     0.05   253.1     2.65    37.38    67.59  0.3166  0.3399    -3.37    -2.44 -0.0796  0.9121  0.0062  0.0064  5.1655  3.867
         60.     0.10   252.1     3.02    37.98    68.04  0.3138  0.3365    -2.76    -1.99 -0.0660  0.9640  0.0035  0.0030  3.2366  2.556
         60.     0.20   250.7     3.58    38.87    68.68  0.3110  0.3333    -1.88    -1.34 -0.0455  1.0063  0.0007 -0.0002  1.5041  1.402
         60.     0.50   248.7     4.36    40.10    69.57  0.3097  0.3324    -0.64    -0.46 -0.0160  1.0109 -0.0007 -0.0010  0.6857  0.598
         60.     0.80   248.1     4.59    40.48    69.84  0.3101  0.3330    -0.27    -0.19 -0.0069  1.0008 -0.0002 -0.0005  0.2996  0.261
         90.     0.02   254.7     2.05    37.41    67.61  0.3179  0.3418    -3.34    -2.41 -0.0782  0.8783  0.0075  0.0084  6.0584  4.455
         90.     0.05   254.1     2.28    37.79    67.89  0.3158  0.3391    -2.96    -2.13 -0.0698  0.9220  0.0054  0.0057  4.5543  3.402
         90.     0.10   253.2     2.61    38.32    68.29  0.3134  0.3361    -2.43    -1.74 -0.0578  0.9678  0.0031  0.0027  2.8578  2.250
         90.     0.20   252.0     3.09    39.10    68.85  0.3110  0.3334    -1.65    -1.17 -0.0399  1.0052  0.0006 -0.0001  1.3221  1.229
         90.     0.50   250.2     3.77    40.18    69.63  0.3098  0.3326    -0.57    -0.40 -0.0140  1.0095 -0.0006 -0.0009  0.5983  0.522
         90.     0.80   249.7     3.97    40.51    69.86  0.3102  0.3331    -0.23    -0.17 -0.0060  1.0007 -0.0002 -0.0004  0.2618  0.229
0    OBSERVER POSITION AT 1/2 OF A 22.5 DEGREE WIND DIRECTION SECTOR FROM THE PLUME CENTERLINE AT THE GIVEN DISTANCE FROM THE SOURCE
         90.     0.02   254.7     2.04    37.40    67.60  0.3179  0.3419    -3.35    -2.42 -0.0784  0.8769  0.0075  0.0084  6.1030  4.486
1
 HISTORY OF PLUME PARCEL AT DOWNWIND DISTANCE =   1.0 KM

     PARCEL     LOCAL        SO2-TO-SO4= CONVERSION RATE (%/HR)        NOX-TO-HNO3 CONVERSION RATE (%/HR)
      AGE        TIME
      (HR)                   H+2S  H+1S  H     H-1S  H-2S  0           H+2S  H+1S  H     H-1S  H-2S  0
       0.1        928        0.00  0.00  0.00  0.00  0.00  0.00        0.00  0.00  0.00  0.00  0.00  0.00
1
 HISTORY OF PLUME PARCEL AT DOWNWIND DISTANCE =   2.0 KM

     PARCEL     LOCAL        SO2-TO-SO4= CONVERSION RATE (%/HR)        NOX-TO-HNO3 CONVERSION RATE (%/HR)
      AGE        TIME
      (HR)                   H+2S  H+1S  H     H-1S  H-2S  0           H+2S  H+1S  H     H-1S  H-2S  0
       0.1        920        0.00  0.00  0.00  0.00  0.00  0.00        0.00  0.00  0.00  0.00  0.00  0.00
       0.3        928        0.00  0.00  0.00  0.00  0.00  0.53        0.00  0.00  0.00  0.00  0.00  3.68
1                                                      PLOT FILE VERIFICATION
0                                                        PLUME-BASED DATA
0     SKY BACKGROUND
0          NX                 1       2
0    DISTANCE (KM)            1       2
0 REDUCTION OF VISUAL
       RANGE (%)           2.888   2.607
0   BLUE-RED RATIO
                           0.990   0.968
0   PLUME CONTRAST AT
       0.55 MICRONS       -0.056  -0.058
0PLUME PERCEPTIBILITY
      DELTA E(L*A*B*)      1.811   2.250

0     WHITE BACKGROUND
0          NX                 1       2
0    DISTANCE (KM)            1       2
0 REDUCTION OF VISUAL
       RANGE (%)           0.000   0.000
0   BLUE-RED RATIO
                           0.000   0.000
```

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1                                                                            PAGE    7

0  PLUME CONTRAST AT
       0.55 MICRONS       0.000   0.000
OPLUME PERCEPTIBILITY
     DELTA E(L*A*B*)      0.000   0.000

0     GRAY BACKGROUND
0           NX              1       2
0    DISTANCE (KM)          1       2
0 REDUCTION OF VISUAL
        RANGE (%)         0.000   0.000
0  BLUE-RED RATIO
                          0.000   0.000
0  PLUME CONTRAST AT
       0.55 MICRONS       0.000   0.000
OPLUME PERCEPTIBILITY
     DELTA E(L*A*B*)      0.000   0.000
1    BLACK BACKGROUND
0           NX              1       2
0    DISTANCE (KM)          1       2
0 REDUCTION OF VISUAL
        RANGE (%)         0.000   0.000
0  BLUE-RED RATIO
                          0.000   0.000
0  PLUME CONTRAST AT
       0.55 MICRONS       0.000   0.000
OPLUME PERCEPTIBILITY
     DELTA E(L*A*B*)      0.000   0.000
```

APPENDIX C

PLUVUE II SOURCE CODE

```
C ********************************************************************

C **********************************************************************
C
C
C                            PLUVUE II
C
C                      PLUME VISIBILITY MODEL
C
C      THIS MODEL WAS DEVELOPED FOR :
C
C                U. S. ENVIRONMENTAL PROTECTION AGENCY
C                  RESEARCH TRIANGLE PARK, NC 27111
C
C      BY
C
C                        DOUGLAS A. LATIMER
C                       ROBERT W. BERGSTROM
C                         CLARK D. JOHNSON
C                            HENRY HOGO
C                        CHRISTIAN SEIGNEUR
C
C                     SYSTEMS APPLICATIONS, INC.
C                       101 LUCAS VALLEY ROAD
C                       SAN RAFAEL, CA 94903
C
C                          (415) 472-4011
C
C      IT IS RECOMMENDED THAT THE USER OF THIS MODEL REFER TO EPA'S
C      SERIES OF TECHNICAL GUIDANCE DOCUMENTS ON VISIBILITY, INCLUDING
C      THE "WORKBOOK FOR ESTIMATING VISIBILITY IMPAIRMENT" AND THE "USERS
C      MANUAL FOR THE PLUME VISIBILITY MODEL (PLUVUE II)", AND THE
C      FOLLOWING DOCUMENTS:
C
C           (1)  U. S. ENVIRONMENTAL PROTECTION AGENCY (OCTOBER,1979),
C                "PROTECTING VISIBILITY:  AN EPA REPORT TO CONGRESS",
C                EPA-450/5-79-008.
C
C           (2)  LATIMER, D. A. ET AL. (SEPTEMBER,1978), "DEVELOPMENT
C                OF MATHEMATICAL MODELS FOR THE PREDICTION OF ANTHROPOGENIC
C                VISIBILITY IMPAIRMENT",EPA-450/3-78-110A,B,C, SYSTEMS
C                APPLICATIONS, INCORPORATED, SAN RAFAEL, CALIFORNIA.
C
C **********************************************************************
C
      SUBROUTINE MAIN
C     PROGRAM PLUVUE(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT,TAPE7)
      COMMON/BCKGND/ ELEV,RVAMB,ACCAMB,AMBNO2,RH,ROVA,ROVC,ROVS,ROVP,
     1SIGA,SIGC,SIGS,SIGP,HPBL,IREAD,CORAMB,AMBNO3,AMBSO4,INTYP
     2,DENA,DENC,DENP,DENS,ROVCAR,SIGCAR,DENCAR,AMBCAR
      DIMENSION SPECR(39),SPECB(39),SPECO(39),SPECP(39)
      COMMON/MIESCT/ROG,SIGMA,NLAMB,LAMB(20),JX,IT,TT(200),DUM(20),
     1PDUM(20,50),DUMA(20),DUMG(20)
      COMMON / OPTDEP / TATOIZ(39),TATHIZ(39),TATOHZ(39),X1(39),
     1X2(39),TAUTDI(39),TAUTOD(39),XHDI(39),XHOD(39)
      COMMON/ MISC/ ABSNO2(39),SOLAR(39),RAD,FORPIN,OMZ(39),OMH(39)
     1,NTHETA,RFR,RFI
      COMMON / RAIN / ITEST,IASD
      COMMON / ISAACS / IRE
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C ********************************************************************

      COMMON/INDREF/RFRSO4,RFISO4,RFRCOR,RFICOR,RFRPRM,RFIPRM
     1,RFRCAR,RFICAR
      COMMON/RADPRP/BTASO4(39),BTACOR(39),BTAPRM(39),BTAAER(39),
     1PAER(39,27),PPRIM(39,27),PSO4(39,27),PCOR(39,27),BTABAC(39)
     2,PCAR(39,27),ABSCAR(39),BTACAR(39),ABSSO4(39),ABSCOR(39),
     3 ABSPRM(39),GSO4(39),GCOR(39),GPRM(39),GCAR(39),GAER(39)
     4,GBAC(39),PBAC(39,27)
      COMMON/COLOR/YCAP,VAL,X,Y,YCAPD,VALD,XD,YD,DELUV,DELAB,
     1XBAR(39),YBAR(39),ZBAR(39),PI,CONT1,CONT2,CONT3,BRATIO
      COMMON /SOL/ EFFDEC, BRANGL
      DIMENSION ALT(6),AA(4),DIST(16),PLANT(6),
     1XPARTI(16,6),XNO2I(16,6),QNO2I(6),XPARTP(16,6),XPARTS(16,6)
      DIMENSION ROBJ(7),REFL(3)
      DIMENSION XQ(6),CHIQTY(6),RSO2(17),RNOX(16),STABLE(7)
      DIMENSION TER(16),OBSPLU(16),AZMUTH(16),AALPHA(16),ABETA(16)
     1,ROBJT(16),ROBJCT(24)
      DIMENSION PLT1(16,4),PLT2(16,4),PLT3(16,4),PLT4(16,4),
     1PLOT1(16,4),PLOT2(16,4),PLOT3(16,4),PLOT4(16,4)
      DIMENSION RSO2R(17,6,17),RNOXR(17,6,17),QSO2TR(6,16),QNOXTR(6,16),
     1 QSO4TR(6,16),QNO3TR(6,16),QPARTT(6,16),RATIOT(6,16),PHIKKR(24),
     1 QJ(24),RNO2X(17,6,17)
      DIMENSION XB(40),XP(40),XR(40)
C
C  IF NUMBER OF DOWNWIND DISTANCES > 16, INCREASE ABOVE DIMENSIONS.
C
      DIMENSION P(7)
      DATA P/0.10,0.15,0.20,0.25,0.30,0.30,0.30/
      DATA AA/30.,45.,60.,90./
      DATA ALT /4HH+2S,4HH+1S,1HH,4HH-1S,4HH-2S,2H 0/
      DATA STABLE/2H A,2H B,2H C,2H D,2H E,2H F,2H G/
      DATA NX1 /1/
      DATA ROBJ/0.02,0.05,0.10,0.20,0.50,0.80,1.0/
      DATA REFL/1.,0.3,0./
C
C  SPECIAL SYSTEM CALL FOR PRIME COMPUTER TO ALLOW PRINT FILE TO EXTEND
C  OUT TO 132 COLUMNS.
C
      CALL ATTDEV(INTS(6),INTS(7),INTS(2),INTS(66))
      PI=3.14159
      RAD=PI/180.
C
C **********************************************************************
C
C READ IN DATA (METEOROLOGICAL, PLANT EMISSIONS, AND AMBIENT AIR QUALITY
C
C **********************************************************************
C
99    CONTINUE
      READ(5,1) (PLANT(J),J=1,6)
1     FORMAT (6A4)
C
C READ IN U(MPH), STABILITY INDEX, LAPSE RATE(DEG F/1000 FT).  I IS
C STABILITY INDEX.  FOR PASQUILL-GIFFORD STABILITY CLASSES,
C I=1 FOR "A", 2 FOR "B", 3 FOR "C", ETC.
C
      READ (5,2) U,I,ALAPSE
      IS=I
C
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C ***********************************************************************

C   IUSPC=0 FOR WIND SPEED ALOFT, NON-ZERO FOR SURFACE.
C   INEW=NEW STABILITY INDEX. NXSTAB IS DOWN WIND DISTANCE INDEX WHERE
C   NEW STABILITY STARTS.  SET NXSTAB TO NX2+1 AND INEW=I FOR NO
C   STABILITY CHANGE.
C
      READ(5,2001)IUSPC,INEW,NXSTAB
2     FORMAT (F5.1,I5,F5.2,F5.1)
C
C  READ INITIAL PLUME HORIZONTAL AND VERTICAL DIMENSIONS
C  FOR A NON-POINT SOURCE.
C
      READ(5,9)YINITL,ZINITL
C
C   READ IN PLANETARY BOUNDARY HEIGHT (MIXING DEPTH) IN METERS.
C   THIS IS THE LIMIT ON VERTICAL MIXING OF EMISSIONS.  IF SET TO ZERO,
C   THERE IS NO LIMIT.
C
      READ(5,7) HPBLM
C
C  SET PBL HEIGHT TO 2 KM FOR BACKGROUND POLLUTANTS FOR OPTICS
C  CALCULATIONS ONLY.
C
      HPBL=2.
C
C   READ IN RELATIVE HUMIDITY IN PERCENT
C
      READ(5,8) RH
C
C   READ INDICATOR FOR TYPE OF STABILITY SCHEME.  IDIS=0 FOR PASQUILL-
C  GIFFORD, 1 FOR TVA.
C
      READ(5,801) IDIS
C
C    FLAGS FOR OPTICS ANALYSIS ROUTINES.  IFLG1=1 FOR HORIZONTAL SIGHT
C    PATH VIEWS.  IFLG2=1 FOR NON-HORIZONTAL SIGHT PATHS.  IFLG3=1 FOR
C    BACKGROUND OBJECT VIEWS.  IFLG4=1 FOR SIGHT PATHS ALONG THE PLUME
C    CENTERLINE. NT1= STARTING INDEX FOR SCATTERING ANGLE ARRAY FOR
C    RADIATIVE TRANSFER AND SCATTERING CALCULATIONS.  NT2= ENDING INDEX
C    FOR SCATTERRING ANGLE CALCULATIONS.  NORMALLY, NT1 IS SET TO 1
C    AND NT2 IS SET TO 7 FOR THE 7 GENERIC SCATTERING ANGLES AND
C    THESE VALUES SHOULD BE USED WHENEVER A OBSERVER-BASED RUN (NC1=1)
C    IS BEING MADE.  FOR A GENERIC CASE RUN, NT1 AND NT2 CAN BE SET
C    TO LIMIT CALCULATIONS FOR LESS THAN THE 7 ANGLES. EXAMPLE:  FOR
C    A GENERIC RUN FOR CALCULATIONS AT 90 DEGREES ONLY, NT1=3 AND
C    NT2=4.  NX2= ENDING INDEX FOR ARRAY OF DOWNWIND DISTANCES OF
C    POINTS FOR OPTICS CALCULATIONS.  NZF=1 FOR CALCULATIONS AT
C    PLUME CENTERLINE ONLY, 2 FOR OPTICS CALCULATIONS AT PLUME
C    CENTERLINE AND AT GROUND LEVEL.
C
      READ(5,2001) IFLG1,IFLG2,IFLG3,IFLG4,NX2,NT1,NT2,NZF
2001  FORMAT(10I2)
C
C  SWITCH FOR TURNING ON PRINT OUT OF TABLE FOR INITIAL PLUME DILUTION.
C  IDILD=0 FOR NO TABLE, 1 FOR TABLE.
C
      READ(5,2001)IDILD
C
C  READ TEST INDEX FOR BSIZE OPTIMIZATION
```

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C ***********************************************************************

C
      ITEST = 0
      IASD = 0
      IRE=1
      IBAC = 0
C
C   READ IN DOWNWIND DISTANCES FOR OPTICS CALULATIONS (KILOMETERS).
C   IT IS RECOMMENDED THAT THE FIRST 4 DOWNWIND DISTANCES BE SET TO
C   1., 2., 5., AND 10. KM.
C
      READ(5,9)(DIST(I),I=1,NX2)
9     FORMAT(8F10.0)
C
C   CONVERT DOWNWIND DISTANCES FROM KILOMETERS TO METERS
C
      DO 32 I=1,NX2
32    DIST(I)=DIST(I)*1000.
C
C    READ IN SO2, NOX, AND PARTICULATE EMISSION RATES IN TONS/DAY
C    FOR ALL STACKS COMBINED.  (SHORT TONS = 2000 LB, NOT METRIC TONS)
C
      READ (5,3) QSO2,QNOX,QPART
C
3     FORMAT (3F10.2)
C
C    READ IN FLUE GAS FLOW RATE PER STACK (CU FT PER MIN), FLUE GAS
C    EXIT TEMPERATURE (DEG F), FLUE GAS OXYGEN CONCENTRATION (MOLE-
C    PERCENT), FLUE GAS EXIT VELOCITY (M/S)
C
      READ (5,4) FLOW,FGTEMP,FGO2,WMAX
4     FORMAT (3F10.1,F10.2)
C
C    READ IN NUMBER OF STACKS AND STACK HEIGHT.
C
      READ (5,5) UNITS,HSTACK
5     FORMAT (2F5.1)
6     FORMAT (F10.0)
C
C    READ IN AMBIENT AIR TEMPERATURE AT STACK HEIGHT.
C
      READ (5,7) TAMB
7     FORMAT (F10.1)
C
C    READ IN AMBIENT BACKGROUND POLLUTANT CONCENTRATION IN PPM
C    OF NOX, NO2, O3, AND SO2.
C
      READ(5,8) AMBNOX,AMBNO2,O3AMB,AMBSO2
8     FORMAT(5F10.3)
C
C    READ IN AEROSOL SIZE DISTRIBUTION DATA.  ROVA=MASS MEAN RADIUS
C    FOR BACKGROUND ACCUMULATION MODE (.1 TO 1 MICROMETER).  ROVC =
C    MASS MEAN RADIUS FOR BACKGROUND COARSE MODE (> 1 MICROMETER).
C    ROVS = MASS MEAN RADIUS FOR PLUME SECONDARY AEROSOL.  ROVP =
C    MASS MEAN RADIUS FOR PLUME PRIMARY AEROSOL.  SIGA = GEOMETRIC
C    STANDARD DEVIATION OF RADIUS OF BACKGROUND ACCUMULATION MODE.
C    SIGC = GEOMETRIC STANDARD DEVIATION OF BACKGROUND COARSE MODE
C    AEROSOL.  SIGS = GEOMETRIC STANDARD DEVIATION OF RADIUS OF
C    PLUME SECONDARY AEROSOL.  SIGP GEOMETRIC STANDARD DEVIATION OF
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C ***********************************************************************

C    RADIUS OF PLUME PRIMARY PARTICULATE.  DENA=DENSITY (G/CM**3) OF
C    BACKGROUND ACCUMULATION MODE AEROSOL.  DENC = DENSITY OF BACKGROUND
C    COARSE MODE AEROSOL.  DENS = DENSITY OF PLUME SECONDARY AEROSOL
C    AND DENP = DENSITY OF PLUME PRIMARY AEROSOL.
C
      READ(5,8) ROVA,ROVC,ROVS,ROVP
      READ(5,8) SIGA,SIGC,SIGS,SIGP
      READ(5,8) DENA,DENC,DENS,DENP
C
C     ROVCAR = MASS MEDIAN RADIUS OF CARBON PARTICULATE.
C     SIGCAR = GEOMETRIC STD DEVIATION OF CARBON PARTICULATE
C     DENCAR = DENSITY OF PLUME CARBON PARTICULATE EMISSIONS.
C     RFR = REAL PART OF INDEX OF REFRACTION FOR AEROSOL SCATTERING.
C     RFI = IMAGINARY PART OF INDEX OF REFRACTION FOR  AEROSOL
C     ABSORPTION.
C     FRACTC = FRACTION OF PARTICULATE MASS EMISSION DUE TO CARBON.
C     AMBCAR = BACKGROUND ATMOSPHERIC  ELEMENTAL CARBON (UG/M3).
C     RFRSO4 = REAL PART OF INDEX OF REFRACTION FOR ACCUMULATION MODE
C     AEROSOL.
C     RFISO4 = IMAGINARY PART OF INDEX OF REFRACTION FOR ACCUMULATION
C         MODE AEROSOL.
C     RFRCAR = REAL PART OF INDEX OF REFRACTION FOR CARBON AEROSOL.
C              (CARBON AEROSOL WITHIN PLUME).
C     RFICAR = IMAGINARY PART OF INDEX OF REFRACTION FOR CARBON
C              AEROSOL (FOR ABSORPTION WITHIN PLUME.)
C   RFRCOR, RFICOR = REAL AND IMAGINARY PARTS OF INDEX OF
C            REFRACTION FOR BACKGROUND SKY COARSE MODE
C            AEROSOL.
C   RFRPRM, RFIPRM = REAL AND IMAGINARY PARTS OF INDEX OF
C            REFRACTION FOR PLUME PRIMARY AEROSOL
C
      READ(5,8)ROVCAR,SIGCAR,DENCAR,FRACTC,AMBCAR
      READ(5,8)RFRSO4,RFISO4,RFRCOR,RFICOR
      READ(5,8)RFRPRM,RFIPRM,RFRCAR,RFICAR
C
C    READ IN AMBIENT COARSE MODE AEROSOL CONCENTRATION  (BACKGROUND,)
C    IN UG/M.
C
      READ(5,8) CORAMB
C
C    INTYP = PARAMETER TO DETERMINE INPUT DATA.  IF INTYP=1,
C    BACKGROUND SO4 AND NO3 CONCENTRATIONS ARE INPUT AND MODEL
C    COMPUTES BACKGROUND VISUAL RANGE.  IF INTYP .NE. ONE,
C    BACKGROUND VISUAL RANGE IS INPUT AND MODEL COMPUTES BACKGROUND
C    ACCUMULATION MODE CONCENTRATION.
C
      READ(5,801) INTYP
 801  FORMAT(I5)
      IF(INTYP.EQ.1) GO TO 802
C
C    READ IN BACKGROUND VISUAL RANGE.
C
      READ(5,8) RVAMB
      GO TO 803
C
C    READ IN BACKGROUND SULFATE AND  NITRATE CONCENTRATIONS. (UG/M**3)
C
 802  READ(5,8) AMBSO4,AMBNO3
```

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C ***********************************************************************

  803 CONTINUE
C
C     READ IN DEPOSITION VELOCITIES. VDSO2 = DEPOSTION VEL FOR SO2.
C     VDNOX = DEPOSITION VELOCITY FOR NOX.  VDCOR = DEP. VEL. FOR
C     COARSE MODE PARTICULATE. VDSUB =DEPOSITION VELOCITY FOR
C     SUB-MICRON PARTICULATE.  UNITS ARE CM/S.
C
      READ(5,806) VDSO2,VDNOX,VDCOR,VDSUB
  806 FORMAT(16F5.2)
C
C    READ IN FLAG FOR SO2-TO-SO4 CONVERSION RATE (IN ADDITION TO OH
C    CHEMISTRY) TO BE CONSTANT WITH DOWNWIND DISTANCE (ICON=0) OR
C    TO CHANGE WITH DISTANCE FROM THE SOURCE (ICON=1).
C
      READ(5,801)ICON
C
C    READ IN SO2-TO-SO4 CONVERSION RATE (%/HR) TO BE ADDED TO RATE
C    CALCULATED FROM OH CHEMISRY.
C
      READ(5,46)RSO2C
 46   FORMAT(8F10.7)
      IF(ICON.EQ.1)GO TO 826
      DO 79 NX=1,NX2
 79   RSO2(NX)=RSO2C
      GO TO 807
C
C  READ IN SO2-TO-SO4 CONVERSION RATE TO BE ADDED TO RATE CALCULATED BY
C  OH MODEL, WITH VALUES CORRESPONDING TO EACH OF THE ANALYSIS POINTS
C  DOWNWIND FROM THE SOURCE.
C
 826  READ(5,46)(RSO2(NX),NX=1,NX2)
  807 CONTINUE
C
C  NC1 AND NC2 CONTROL OUTPUT
C  NC1=1,NC2=1 FOR STANDARD TABLES ONLY (NOT SITE SPECIFIC)
C  NC1=2,NC2=2 FOR SITE SPECIFIC TABLES ONLY
C  NC1=1, NC2=2 FOR BOTH TABLES-- SITE SPECIFIC AND STANDARD
C
      READ(5,808)NC1,NC2
      IF(NC1.EQ.2)GO TO 825
C
C   READ IN INDICES FOR CONTROLLING PLUME-BASED DATA SAVED FOR PLOTTING.
C
      READ(5,2001)NPP,NAP,NTP,NZP,IO1P,IPP
 825  IF(NC2.EQ.1)GO TO 816
C
C    FOR RUNS WITH SPECIFIC CASE CALCULATIONS, INCREASE NUMBER OF
C    SCATTERING ANGLES FOR ALL THE SPECIFIC VIEWER LINE-OF-SIGHT
C    GEOMETRIES.
C
      NTHETA=7+NX2
C
C    READ IN OBSERVER POSITION:  UTM X-COORDINATE (KM), UTM Y-COORDINATE
C    (KM), ELEVATION (FT,MSL) FOR OBSERVER-BASED CALCULATIONS.
C
      READ(5,4)XOBS,YOBS,ZOBS
C
C    READ IN SOURCE POSITION:  UTM X-COORDINATE, Y-COORDINATE, ELEVATION
```

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C ***************************************************************************

C    FOR ALL RUNS.
C
816   READ(5,4)XSTACK,YSTACK,ZSTACK
C
C    READ UTM GRID ZONE NUMBER, MONTH, DAY, TIME (24 HOUR MILITARY),
C     TIME ZONE NUMBER, AND YEAR.
C   IZONE IS THE UNIVERSAL TRANSVERSE MERCATOR GRID ZONE NUMBER
C   READ FROM A USGS MAP
C   TZONE IS THE TIME ZONE NUMBER, COUNTING WEST FROM GREENWICH,
C   ADD ONE FOR DAYLIGHT SAVINGS TIME.
C
       READ(5,808)IZONE,IMO,IDAY, TIME,TZONE,IYEAR
  808 FORMAT(3I5,2F5.0,I5)
C
C    SKIP OVER READ STATEMENTS IF RUN IS FOR A PLUME-BASED CASE ONLY.
C
      IF(NC2.EQ.1)GO TO 818
C
C    READ IN ELEVATION OF TERRAIN AT EACH DOWNWIND POINT (FT MSL). IF
C    TER(1)=0, MODEL SETS UP FLAT TERRAIN FOR ALL POINTS.  THESE CHANGES
C    ARE USED ONLY IN THE CALCULATION OF THE ELEVATION ANGLE BETA OF THE
C    SPECIFIC LINES OF SIGHT USED FOR THE OBSERVER-BASED CALCULATIONS.
C    THE GAUSSIAN DISPERSION CALCULATIONS USE FLAT TERRAIN.
C
      READ(5,809) (TER(I),I=1,NX2)
      IF(TER(1).NE.0.) GO TO 8080
      DO 8079 I=1,NX2
      TER(I)=ZSTACK
 8079 CONTINUE
 8080 CONTINUE
C
C    READ IN BACKGROUND OBJECT DISTANCES FROM OBSERVER THROUGH PLUME
C    TO BACKGROUND TERRAIN FOR LINE-OF-SIGHT AZIMUTHS OF 15 DEG.,
C    30 DEG., 45 DEG., ... , 360 DEG.  THE DISTANCE FOR EACH LINE-
C    OF-SIGHT AZIMUTH ACTUALLY USED IS INTERPOLATED FROM THESE VALUES.
C    IF ROBJCT(I) = 0, THE OBJECT DISTANCE IS SET EQUAL TO THE PLUME-
C    OBSERVER DISTANCE ALONG THE LINE-OF-SIGHT TO THE ITH DOWNWIND POINT.
C
      READ(5,809) (ROBJCT(NAZ),NAZ=1,24)
  809 FORMAT(8F10.1)
C
C    READ IN WIND DIRECTION IN DEGREES FROM NORTH (FROM WHICH WIND IS
C    BLOWING).
C
      READ(5,7)WIND
818   WRITE (6,10)
10    FORMAT (1H1)
      WRITE  (6,11) (PLANT(J),J=1,6)
11    FORMAT (30H VISUAL IMPACT ASSESSMENT FOR ,6A4//)
      WRITE (6,12) ZSTACK
12    FORMAT (5X,21HEMISSIONS SOURCE DATA//10X,20HELEVATION OF SITE = ,
     1 F10.0,10H  FEET MSL)
C
C CONVERT ELEVATION FROM FEET TO METERS
C
      ELEV = ZSTACK/3.281
      WRITE (6,13) ELEV
 13   FORMAT (30X,F10.0,12H  METERS MSL,/)
```

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C ***********************************************************************

      WRITE (6,14) UNITS
 14   FORMAT (10X,15HNO. OF UNITS = ,F6.0,/)
      WRITE (6,15) HSTACK
 15   FORMAT (10X,15HSTACK HEIGHT = ,F5.0,6H  FEET)
C
C CONVERT STACK HEIGHT FROM FEET TO METERS
C
      HSTACK = HSTACK/3.281
      WRITE (6,16) HSTACK
 16   FORMAT (25X,F5.0,8H  METERS,/)
      WRITE (6,17) FLOW
 17   FORMAT(10X,21HFLUE GAS FLOW RATE = ,F10.0,11H  CU FT/MIN)
C
C CONVERT FLUE GAS FLOW RATE FROM CU FT/MIN TO CU METERS/SEC
C
      FLOW = FLOW/(3.281**3.*60.)
      WRITE (6,18) FLOW
 18   FORMAT (31X,F10.2,10H  CU M/SEC,/)
      WRITE (6,19) FGTEMP
 19   FORMAT (10X,23HFLUE GAS TEMPERATURE = ,F10.0,3H  F)
C
C CONVERT FLUE GAS TEMPERATURE FROM F TO K
C
      FGTEMP = (FGTEMP+459.67)/1.8
      WRITE (6,20) FGTEMP
 20   FORMAT(33X,F10.0,3H  K,/)
      WRITE (6,21) FGO2
 21   FORMAT(10X,26HFLUE GAS OXYGEN CONTENT = ,F10.1,13H  MOL PERCENT,/)
C
C CONVERT FGO2 IN MOL PERCENT TO QO2 IN PPM BY VOLUME
C
      QO2 = FGO2*1.E4
      WRITE (6,22) QSO2
22    FORMAT (10X,28HSO2 EMISSION RATE (TOTAL) = ,F10.2,
     1        10H  TONS/DAY)
C
C CONVERSION FACTOR TONS/DAY TO GRAMS PER SEC
C
      C1 = 2000.*453.6/(24.*3600.)
      QSO2 = QSO2*C1
      WRITE (6,23) QSO2
 23   FORMAT (38X,1PE12.3,7H  G/SEC,/)
      WRITE (6,24) QNOX
24    FORMAT (10X,35HNOX EMISSION RATE (TOTAL,AS NO2) = ,F10.2,
     1       10H  TONS/DAY)
      QNOX = QNOX*C1
      WRITE (6,231) QNOX
 231  FORMAT(45X,1PE12.3,7H  G/SEC,/)
      WRITE (6,25) QPART
25    FORMAT (10X,36HPARTICULATE EMISSION RATE (TOTAL) = ,F10.2,
     1       10H  TONS/DAY)
      QPART = QPART*C1
      WRITE(6,231) QPART
      WRITE(6,10)
      WRITE (6,26) U
26    FORMAT (///5X,43HMETEOROLOGICAL AND AMBIENT AIR QUALITY DATA//10X,
     1              12HWINDSPEED = ,F5.1,10H  MILES/HR)
C
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C ***********************************************************************


C CONVERT WIND SPEED FROM MILES/HR TO M/SEC
C
      U = U*0.447
      WRITE (6,27) U
      WRITE(6,271)
      IF(IDIS.EQ.9) WRITE(6,281)
  281 FORMAT(10X,45HDISPERSION COEFFICIENTS ARE USER-INPUT VALUES)
      I=IS
      IF(IDIS.EQ.1) WRITE(6,282) I
  282 FORMAT(10X,19HTVA STABILITY INDEX,I2)
      IF(IDIS.EQ.0) WRITE(6,283) STABLE(I)
  283 FORMAT(10X,42HPASQUILL-GIFFORD-TURNER STABILITY CATEGORY,A2)
  27  FORMAT(1H ,21X,F5.1,7H  M/SEC)
      WRITE(6,271)
  271 FORMAT(5X)
 28   FORMAT (10X,18HSTABILITY INDEX = ,I2)
      WRITE (6,29) ALAPSE
  29  FORMAT(10X,13HLAPSE RATE = ,F5.2,11H  F/1000 FT)
C
C CONVERT LAPSE RATE FROM F/1000 FT TO K/M
C
      ALAPSE = ALAPSE*3.281/(1000.*1.8)
      WRITE (6,30) ALAPSE
  30  FORMAT (23X,1PE12.3,5H  K/M,/)
C
C CONVERT TO POTENTIAL TEMPERATURE BY ADDING DRY ADIABATIC LAPSE RATE
C
      ALAPSE = ALAPSE + 9.8E-3
C
C    TO PREVENT POSSIBLE DIVIDE BY ZERO IN CALCULATION OF STABILITY
C    PARAMETER S IN PLUME RISE,CHECK IF ALAPSE = 0.
C
      IF(ALAPSE.EQ.0.)ALAPSE=.1E-30
      WRITE (6,31) ALAPSE
 31   FORMAT (10X,35HPOTENTIAL TEMPERATURE LAPSE RATE = ,1PE12.3,
     1        5H  K/M,/)
      WRITE (6,33) TAMB
  33  FORMAT(10X,22HAMBIENT TEMPERATURE = ,F5.1,3H  F)
C
C CONVERT AMBIENT TEMPERATURE FROM F TO K
C
      TAMB = (TAMB + 459.67)/1.8
      WRITE (6,34) TAMB
  34  FORMAT(32X,F5.1,3H  K,/)
      WRITE(6,341) RH
      RH=RH/100.
  341 FORMAT(10X,20HRELATIVE HUMIDITY = ,F5.1,3H  %,/)
      WRITE(6,342) HPBLM
  342 FORMAT(10X,15HMIXING DEPTH = ,F5.0,3H  M,/)
C
C  CALCULATION OF AMBIENT PRESSURE IN ATMOSPHERES FROM ELEVATION IN M MSL
C
      PAMB = EXP(-1.15E-4*ELEV)
C
C  CALCULATE WATER CONCENTRATION IN PPM
C
      WATER =(6030.*RH/PAMB)*EXP(4884.*(1./273.-1./TAMB))
      WRITE (6,40) PAMB
```

```
C ***********************************************************************

       WRITE(6,271)
 40    FORMAT (10X,19HAMBIENT PRESSURE = ,F5.2,5H  ATM)
       WRITE (6,35) AMBNOX
       WRITE(6,271)
 35    FORMAT (10X,31HBACKGROUND NOX CONCENTRATION = ,F10.3,5H  PPM)
C
C      CONVERT UTM COORDINATES TO LAT, LONG.
C      XSTACK = UTM EAST COORD., YSTACK= UTM NORTH COORD.
C  IZONE= UTM ZONE NUMBER
C      ALON=LONGITUDE IN DEGREES, ALAT= LATITUDE IN DEGREES
C
       CALL MAPUTG(XSTACK,YSTACK,IZONE,ALON,ALAT)
C CHANGE SIGN OF LONGITUDE TO MATCH THE POSITIVE DIRECTION
C ASSUMED IN SOLARZ, WHERE POSITIVE INCREASING IS FROM EAST
C TO WEST STARTING FROM THE GREENWICH MERIDIAN. MAPUTG HAS
C LONGITUDE INCREASING POSITIVE FROM WEST TO EAST STARTING
C FROM THE GRENWICH MERIDIAN, AND IT RETURNS NEGATIVE
C VALUES OF LONGITUDE FOR THE U.S.
C
       ALON = -1.*ALON
C
C CALCULATE SOLAR ZENITH ANGLE.
C
       TIME1=CLOCK(TIME,-2)
       CALL SOLARZ(ALAT,ALON,TZONE,IYEAR,IMO,IDAY,TIME1,SUNEL,5)
       SINAL=COS(EFFDEC)*SIN(HRANGL)/SIN((90.-SUNEL)*RAD)
       CALL SOLARZ(ALAT,ALON,TZONE,IYEAR,IMO,IDAY, TIME,SUNELE,5)
       ZENITH=90.-SUNELE
C
C     CALCULATE SOLAR AZIMUTH ANGLE FOR LATE AM
C
       SINA=COS(EFFDEC)*SIN(HRANGL )/SIN(ZENITH*RAD)
       SUNAZ=180.-ASIN(SINA)/RAD
C
C   SUN AZIMUTH FOR EARLY AM
C
       IF(TIME .LT. 1030. .AND. SINA .GT. SINAL)SUNAZ=ASIN(SINA)/RAD
C
C   SUN AZIMUTH FOR EARLY PM
C
       IF(TIME .GT. 1030. .AND. SINA .GT. SINAL)SUNAZ=180.+ASIN(SINA)/RAD
C
C   SUN AZIMUTH FOR LATE PM
C
       IF(TIME .GT. 1430. .AND. SINA .LT. SINAL)SUNAZ=360.-ASIN(SINA)/RAD
C
C     CALCULATE DYNAMIC EQUILIBRIUM CONSTANT FOR NO2 - NO
C     BRANCH IF ZENITH > 90 DEGREES AND SET CONSTANT TO ZERO.
C
       IF(ZENITH.GE.90.) GO TO 351
       PHIKK=[illegible]1.E-2/0.44)*EXP(-0.38/COS(PI/180.*ZENITH))
       GO TO 352
 351   PHIKK=0.0
 352   CONTINUE
       SUM=AMBNOX+AMBNO2+O3AMB+PHIKK
       XNO2=0.5*(SUM-SQRT(SUM*SUM-4.*AMBNOX*(O3AMB+AMBNO2)))
       IF(XNO2.GT.AMBNOX) XNO2=AMBNOX
       DIF=XNO2-AMBNO2
```

```
C *********************************************************************

      AMBNO2=XNO2
      IF(DIF.GT.0.0005) GO TO 352
      WRITE (6,36) AMBNO2
      WRITE(6,271)
 36   FORMAT (10X,31HBACKGROUND NO2 CONCENTRATION = ,F10.3,5H  PPM)
      WRITE (6,37) O3AMB
      WRITE(6,271)
 37   FORMAT (10X,33HBACKGROUND OZONE CONCENTRATION = ,F10.3,5H  PPM)
      WRITE(6,370) AMBSO2
  370 FORMAT(10X,31HBACKGROUND SO2 CONCENTRATION = ,F10.3,5H  PPM,/)
      ELEV=ELEV/1000.
  811 CONTINUE
      IF(IUSFC.EQ.0)GO TO 817
C
C  CORRECT 7 METER WIND TO STACK HEIGHT
C
      USFC=U
      IF(IDIS.EQ.1)GO TO 821
C
C   CORRECTION IF PASQUILL-GIFFORD STABILITY CLASS
C
      U=USFC*(HSTACK/7.)**P(I)
      GO TO 817
 821  CONTINUE
C
C   CORRECTION IF TVA STABILTY CLASS
C
      P(1)=0.25
      DO 822 II=2,6
 822  P(II)=0.30
      U=USFC*(HSTACK/7.)**P(I)
C
C     PLUME RISE CALCULATION (FROM CRSTER MANUAL (BRIGGS))
C     BOUYANCY FLUX
C
  817 F=(9.8*FLOW/PI)*(PGTEMP-TAMB)/PGTEMP
C
C     PLUME RISE FOR STABLE CONDITIONS
C     STABILITY PARAMETER S
C
      S=(9.8/TAMB)*ALAPSE
      SMIN=(9.8/TAMB)*9.8E-4
      IF(S.LT.SMIN)GO TO 812
      XFINAL=PI*U/SQRT(S)
      RISE =2.6*(F/(U*S))**0.333334
      RISE2=5.*(F**0.25)*(S**(-3./8.))
      IF(RISE2.LT.RISE )RISE=RISE2
      GO TO 815
  812 IF(F.GE.55.)GO TO 813
      XSTR=14.*F**(5./8.)
      GO TO 814
  813 XSTR=34.*F**(2./5.)
 814  XFINAL=3.5*XSTR
      IF(XFINAL.LE.0.0)XFINAL=0.0
      RISE=1.6*(F**0.333334)*((3.5*XSTR)**.666667)/U
  815 H=HSTACK+RISE
C
C  CORRECT 7 METER WIND SPEED TO FINAL PLUME HEIGHT
```

```
C ********************************************************************
C
      IF(IUSFC.EQ.0)GO TO 823
      U=USFC*(H/7.)**P(I)
  823 CONTINUE
C
C     SKIP OVER SIT SPECIFIC GEOMETRY IF RUN IS FOR PLUME-BASED
C     CALCULATIONS ONLY.
C
      IF(NC2.EQ.1)GO TO 820
C
C     CONVERT WIND TO AZIMUTH OF PLUME TRAGECTORY IN RADIANS.
C
      WIND=(WIND-180.)*RAD
C
C     CALCULATE OBSERVER AZIMUTH ANGLE, ELEVATION ANGLE (ABETA),
C     AND HORIZONTAL ANGLE BETWEEN LINE-OF-SITE AND PLUME CENTERLINE
C     FOR EACH DOWNWIND POINT (AALPHA).
C
      DO 810 I=1,NX2
C
C     XPLUME = X COORDINATE OF DOWNWIND POINT IN KILOMETERS.
C     YPLUME = Y COORDINATE OF DOWNWIND POINT IN KILOMETERS.
C     ZPLUME = ELEVATION OF PLUME PARCEL (FT, MSL)
C     OBSPLU(I) = DISTANCE IN KM FROM OBSERVER TO PLUME AT
C     DOWNWIND POINT I.
C
      XPLUME= XSTACK+DIST(I)/1000. *SIN(WIND)
      YPLUME= YSTACK+DIST(I)/1000. *COS(WIND)
      ZPLUME=H*3.281+TER(I)
      OBSPLU(I)=((XPLUME-XOBS)**2+(YPLUME-YOBS)**2+((ZPLUME-ZOBS)/3.281/
     1 1000.)**2)**0.5
C
C     CALCULATE DELTAX, DELTAY AND DELTAZ BETWEEN PLUME PARCEL AND
C     AND OBSERVER POSITION.
C
      DELTAX=XPLUME-XOBS
      DELTAY=YPLUME-YOBS
      DELTAZ=(ZPLUME-ZOBS)/3281.
C
C     CALCULATE AZIMUTH OF OBSERVER SIGHTLINE.
C
      AZMUTH(I)=ATAN2(DELTAX,DELTAY)/RAD
      IF(AZMUTH(I).LT.0.)AZMUTH(I)=AZMUTH(I)+360.
      AALPHA(I)=ACOS(COS(WIND)*COS(AZMUTH(I)*RAD)+SIN(WIND)*SIN(
     1 AZMUTH(I)*RAD))/RAD
      IF (AALPHA(I).GT.90.)AALPHA(I)=180.-AALPHA(I)
C
C     CALCULATION OF SCATTERING ANGLE BETWEEN DIRECT SOLAR RAY AND
C     OBSERVER LINE-OF-SIGHT FOR EACH DOWNWIND POINT.
C
      X1A=(DELTAX*SIN(SUNAZ*RAD)+DELTAY*COS(SUNAZ*RAD))*SIN(ZENITH
     1 *RAD)+DELTAZ*COS(ZENITH*RAD)
      X2A=OBSPLU(I)
      TT(I+7)=ACOS(X1A/X2A)/RAD
C
C     CALCULATION OF ANGLE OF OBSERVER LINE-OF-SIGHT ABOVE HORIZON.
C
      ABETA(I)=ASIN(DELTAZ/OBSPLU(I))/RAD
```

```
C **********************************************************************


C
C   INTERPOLATION OF DISTANCE TO BACKGROUND TERRAIN FOR THE AZIMUTH
C   OF THE SPECIFIC LINE OF SIGHT FOR EACH DOWNWIND DISTANCE.  IF
C   ROBJCT(I)=0., SET ROBJT(I)=OBSPLU(I).
C
       IF(ROBJCT(I).EQ.0.)GO TO 824
       IF(AZMUTH(I).LT.15.)GO TO 805
       DO 804 IAZZ=1,23
       IAZ=IAZZ+1
       AZU=FLOAT(IAZZ)*15.
       AZUM=FLOAT(IAZ)*15.
       IF(AZMUTH(I).GE.AZU.AND.AZMUTH(I).LT.AZUM)GO TO 819
 804   CONTINUE
C
C   SPECIAL CALCULATION FOR AZIMUTH .LT. 15 DEGREES.
C
 805   ROBJT(I)=ROBJCT(24)+(ROBJCT(1)-ROBJCT(24))*(AZMUTH(I)/15.)
       GO TO 810
 819   ROBJT(I)=ROBJCT(IAZZ)+(ROBJCT(IAZ)-ROBJCT(IAZZ))*((AZMUTH(I)-AZU)
      1 /15.)
       GO TO 810
 824   ROBJT(I)=0.
  810 CONTINUE
  820 CONTINUE
C
C *************************************************************************
C
C    CALCULATE BACKGROUND RADIATION CHARACTERISTICS :  SCATTERING,
C    ABSORPTION, AND EXTINCTION COEFFICIENTS AND OPTICAL DEPTHS.
C    ******CALL INRAD*******
C
C *************************************************************************
C
      CALL INRAD(ZENITH)
C
C     DIAGNOSTIC PRINT OUT FOR DEBUGGING ***************
C
C     WRITE(6,225)TATOIZ(19),TATHIZ(19),TATOHZ(19),X1(19),X2(19),
C    1 TAUTDI(19),TAUTOD(19),XHDI(19),XHOD(19)
 225  FORMAT(1H ,3X,'TATOIZ(19) = ',E9.3,', TATHIZ(19) = ',E9.3,
     1 ', TATOHZ(19) = ',E9.3,', X1(19) = ',E9.3,', X2(19) = ',
     2 E9.3,', TAUTDI(19) = ',E9.3,', TAUTOD(19) = ',E9.3,
     3 'XHDI(19) = ',E9.3,', XHOD(19) = ',E9.3)
C     WRITE(6,226)
 226  FORMAT(1H ,7X,'I',4X,'BTASO4',4X,'BTACOR',4X,'BTAPRM',4X,
     1  'BTAAER',4X,'BTABAC',4X,'ABSCAR',4X,'BTACAR',4X,'ABSSO4',
     2 4X,'ABSCOR',4X,'ABSPRM')
C     DO 228 I=1,39
C     WRITE(6,227)I,BTASO4(I),BTACOR(I),BTAPRM(I),BTAAER(I),BTABAC(I),
C    1  ABSCAR(I),BTACAR(I),ABSSO4(I),ABSCOR(I),ABSPRM(I)
 227  FORMAT(1H ,6X,I2,2X,10(E9.3,1X))
 228  CONTINUE
C
C  ************************
C
      WRITE(6,371) CORAMB
 371  FORMAT(///,10X,39HBACKGROUND COARSE MODE CONCENTRATION = ,F10.1,7H  UG
     1  UG/M3,/)
```

```
C *********************************************************************
      WRITE(6,372) AMBSO4
  372 FORMAT(10X,35HBACKGROUND SULFATE CONCENTRATION = ,F10.1,7H  UG/M3,
     1/)
      WRITE(6,373) AMBNO3
  373 FORMAT(10X,35HBACKGROUND NITRATE CONCENTRATION = ,F10.1,7H  UG/M3,
     1/)
      WRITE(6,38) RVAMB
   38 FORMAT(10X,26HBACKGROUND VISUAL RANGE = ,F10.1,12H  KILOMETERS,/)
      WRITE(6,374) VDSO2
  374 FORMAT(10X,26HSO2 DEPOSITION VELOCITY = ,F10.2,8H  CM/SEC,/)
      WRITE(6,375) VDNOX
  375 FORMAT(10X,26HNOX DEPOSITION VELOCITY = ,F10.2,8H  CM/SEC,/)
      WRITE(6,376) VDCOR
  376 FORMAT(10X,41HCOARSE PARTICULATE DEPOSITION VELOCITY = ,F10.2,8H
     1CM/SEC,/)
      WRITE(6,377) VDSUB
  377 FORMAT(10X,44HSUBMICRON PARTICULATE DEPOSITION VELOCITY = ,F10.2,
     18H  CM/SEC,/)
      WRITE(6,271)
      WRITE(6,310)
  310 FORMAT(39X,18HAEROSOL STATISTICS)
      WRITE(6,271)
      WRITE(6,312)
  312 FORMAT(36X,10HBACKGROUND,32X,5HPLUME)
      WRITE(6,271)
  313 FORMAT(25X,12HACCUMULATION,11X,6HCOARSE,11X,12HACCUMULATION,11X,6H
     1COARSE,11X,12HCARBONACEOUS)
      WRITE(6,313)
      WRITE(6,314)
  314 FORMAT(10X,11HMASS MEDIAN,8X,4HMODE,16X,4HMODE,16X,4HMODE,16X,4HMO
     1DE,16X,8HAEROSOLS)
      WRITE(6,315)
  315 FORMAT(10X,6HRADIUS)
      WRITE(6,316)ROVA,ROVC,ROVS,ROVP,ROVCAR
  316 FORMAT(10X,11HMICROMETERS,5X,F10.3,4(10X,F10.3))
      WRITE(6,271)
      WRITE(6,317)
  317 FORMAT(10X,9HGEOMETRIC)
      WRITE(6,318)
  318 FORMAT(10X,8HSTANDARD)
      WRITE(6,319)SIGA,SIGC,SIGS,SIGP,SIGCAR
  319 FORMAT(10X,9HDEVIATION,7X,F10.3,4(10X,F10.3))
      WRITE(6,271)
      WRITE(6,320)
  320 FORMAT(10X,8HPARTICLE)
      WRITE(6,321)
  321 FORMAT(10X,7HDENSITY)
      WRITE(6,322)DENA,DENC,DENS,DENP,DENCAR
  322 FORMAT(10X,9HG/(CM**3),7X,F10.3,4(10X,F10.3))
      WRITE(6,10015) FRACTC
      WRITE(6,10016) AMBCAR
10015 FORMAT(/,53HCARBONACEOUS FRACTION OF PARTICLATE MASS EMISSIONS = ,
     2F10.3,/)
10016 FORMAT(42HBACKGROUND ATMOSPHERIC ELEMENTAL CARBON = ,F10.3,
     28H UG/M**3,/)
      IF(NC2.EQ.1) GO TO 387
      WRITE(6,10)
      WRITE(6,378)
```

```
C ********************************************************************


  378 FORMAT(///5X,57HGEOMETRY OF USER-SPECIFIED PLUME-OBSERVER-SUN ORIE
     1NTATION,//)
      WIND=WIND/RAD+180.
      WRITE(6,379)WIND
  379 FORMAT(10X,26HWIND DIRECTION (DEGREES) =,F5.1/)
387   WRITE(6,271)
      WRITE(6,380) TIME,IMO,IDAY
  380 FORMAT(10X,18HSIMULATION IS FOR ,F5.0,10H HOURS ON ,I2,1H/,I2,/)
      WRITE(6,381)ZENITH
  381 FORMAT(10X,30HSOLAR ZENITH ANGLE (DEGREES) =,F5.1,/)
      WRITE(6,382)SUNAZ
  382 FORMAT(10X,31HSOLAR AZIMUTH ANGLE (DEGREES) =,F8.1,///)
C
C    SKIP OVER SPECIFIC CASE DATA IF RUN IS FOR A PLUME-BASED
C    CALCULATION ONLY.
C
      IF(NC2.EQ.1) GO TO 386
      WRITE(6,383)
  383 FORMAT(10X,83HGEOMETRIES FOR LINES-OF-SIGHT THROUGH PLUME PARCELS
     1AT GIVEN DOWNWIND DISTANCES (X),//,4X,6HX (KM),3X, 7HAZIMUTH,
     2 8X,2HRP,5X,5HALPHA,6X,4HBETA,5X,5HTHETA)
      DO 385 NX=1,NX2
      XPLUME=DIST(NX)/1000.
      WRITE(6,384)XPLUME,AZMUTH(NX),OBSPLU(NX),AALPHA(NX),ABETA(NX),
     1 TT(NX+7)
  384 FORMAT(6F10.1)
  385 CONTINUE
  386 CONTINUE
C
C*****
C***  WRITE OUT THE HEADER PAGE
C*****
      WRITE(6,10000)
10000 FORMAT(1H1,30X,21HBACKGROUND CONDITIONS,//)
      WRITE(6,10200)
10200 FORMAT(1H ,4X,17HACCUMULATION MODE,24X,20HCOARSE PARTICLE MODE,23X
     1,21HPRIMARY PARTICLE MODE)
      WRITE(6,10300)
10300 FORMAT(1H ,4X,11HMASS RADIUS,4X,5HSIGMA,3X,13HBSCAT.55/MASS,8X,
     1 11HMASS RADIUS,4X,5HSIGMA,3X,13HBSCAT.55/MASS,8X,11HMASS RADIUS,
     2 4X,5HSIGMA,3X,13HBSCAT.55/MASS)
      WRITE(6,10400) ROVA,SIGA,BTASO4(19),ROVC,SIGC,BTACOR(19),ROVP,
     1SIGP,BTAPRM(19)
10400 FORMAT(1H ,3E13.4,6X,3E13.4,5X,3E13.4)
10600 FORMAT(1H ,3X,5HNOX =,E10.4,7H  NO2 =,E10.4,7H  NO3 =,E10.4,7H  SO
     12 =,E10.4,7H  SO4 =,E10.4,6H  O3 =,E10.4,5HACC =,E10.4,5HCOR =,
     1E10.4)
      WRITE(6,10010)
      WRITE(6,10011) RFRSO4,RFISO4
      WRITE(6,10012) RFRCOR,RFICOR
      WRITE(6,10013) RFRPRM,RFIPRM
      WRITE(6,10014) RFRCAR,RFICAR
10010 FORMAT(///,50X,18HREFRACTION INDEXES,//)
10011 FORMAT(5X,24HACCUMULATION MODE      = ,E13.4,5H + I ,E13.4,/)
10012 FORMAT(5X,24HCOARSE MODE            = ,E13.4,5H + I ,E13.4,/)
10013 FORMAT(5X,24HPRIMARY AEROSOLS       = ,E13.4,5H + I ,E13.4,/)
10014 FORMAT(5X,24HCARBONACEOUS AEROSOLS = ,E13.4,5H + I ,E13.4,/)
      WRITE(6,271)
```

```
C ***********************************************************************

      WRITE(6,10700)
10700 FORMAT(1H ,30X,40HCOEFFICIENTS AT 0.55 MICROMETERS , 1./KM)
      BTARAY = 0.01162*EXP(-ELEV/9.8)
C
C     BTARAY = RAYLEIGH SCATTERING COEFFICIENT.
C
      ABNO2T = ABSNO2(19)*AMBNO2
C
C    ABNO2T = ABSORPTION COEFFICIENT FOR NO2 AT .55 MICROMETERS
C    BTAAER(19) = BACKGROUND AEROSOL EXTINCTION COEFFICIENT AT
C    .55 MICROMETERS.
C    BTABAC(19) = BACKGROUND EXTINCTION COEFFICIENT AT .55
C    MICROMETERS.  THIS SUMS THE RAYLEIGH AND AEROSOL SCATTERING
C    AND NO2 ABSORPTION.
C
      WRITE(6,10800 ) BTARAY,BTAAER(19),ABNO2T,BTABAC(19)
10800 FORMAT(1H ,6X,8HBTARAY =,E10.4,3X,8HBTAAER =,E10.4,3X,8HABSNO2 =,
     1 E10.4,3X,8HBTABAC =,E10.4,//)
C***  WRITE(6,10900)
10900 FORMAT(1H ,4X,40HNO.  WAVELN   TATOIZ     TATODI    PAER ,7F10.2)
C***  WRITE(6,271)
C
C    LOOP ON WAVELENGTH
C
      DO 20000 I = 1,39
C
C    WAVE = WAVELENGTH (MICROMETERS)
C
      WAVE = 0.36 + 0.01*FLOAT(I)
C
C    TAUTOD(I) = OPTICAL DEPTH FROM SFC TO TOP OF MIXED LAYER,
C    TAUTDI(I) = OPTICAL DEPTH FROM TOP OF MIXED LAYER TO TOP OF
C    ATMOSPHERE.
C    TATODI = OPTICAL DEPTH FROM SFC TO TOP OF ATMOSPHERE FOR THE
C    ITH WAVELENGTH.
C    PAER(I,J) = MIE SCATTERING PHASE FUNCTION FOR THE ITH
C    WAVELENGTH AND THE JTH SCATTERING ANGLE.
C
      TATODI = TAUTOD(I) + TAUTDI(I)
C***  WRITE(6,11000 ) I,WAVE,TATOIZ(I),TATODI,(PAER(I,J),J=1,NTHETA)
20000 CONTINUE
11000 FORMAT(1H ,I5 ,10E11.4)
C
C    CALCULATE PERFECT DIFFUSE REFLECTOR PROPERTIES.
C
      CALL PERDIF(SPECR,ZENITH)
C     WRITE(6,40010)
C***  WRITE(6,40020)
40010 FORMAT(1H1,4X,62HVISUAL EFFECTS CAUSED BY BACKGROUND ATMOSPHERE (W
     1ITHOUT PLUME))
40020 FORMAT(5X,23H*** CLEAR SKY VIEWS ***,//)
40025 FORMAT(/,5X,17HELEVATION (KM) = ,F5.1,5X,20HVISUAL RANGE (KM) = ,
     1F5.0,5X,15HACCUMULATION = ,F5.1,5X,17HNO2 CONC (PPM) = ,F5.2,/)
C***  WRITE(6,40030)
40030 FORMAT(6H THETA,5H BETA,4X,3HTAU,4X,4HYCAP,7X,1HL,7X,1HX,7X,1HY,8H
     1 DELYCAP,4X,4HDELL,2X,6HC(400),2X,6HC(550),2X,6HC(700),2X,6HRATIO
     2,4X,4HDELX,4X,4HDELY,2X,6HE(LUV),2X,6HE(LAB))
      IF(NC1.EQ.2)GO TO 44120
```

```
C **********************************************************************

         DO 40100 I=1,6
C
C     LOOP FOR 6 PLUME-BASED SCATTERING ANGLES
C
C        ITHETA = 4
         ITHETA =I+1
         THETA=TT(ITHETA)
         IFLAGP=0
C
C     LOOP FOR 6 PLUME-BASED SIGHTLINE ELEVATION ANGLES
C
         DO 40100 IBETA=1,7
         BETA=FLOAT(IBETA-1)*15.
C
C     SPECR = RAYLEIGH ATMOSPHERE INTENSITIES
C     SPECB = BACKGROUND ATMOSPHERE INTENSITIES.
C     CALCULATE RAYLEIGH ATMOSPHERE INTENSITIES FOR 39 WAVELENGTHS
C
C        IF(IBAC.GT.0) GO TO 481
         CALL RAYREF   (ZENITH,BETA,THETA, ITHETA, SPECR)
C
C     CALCULATE BACKGROUND ATMOSPHERE INTENSITIES FOR 39 WAVELENGTHS
C
         CALL BACCLN(ZENITH, BETA, THETA,ITHETA, SPECB)
C
C     CALCULATE VISUAL PERCEPTIBILITY PARAMETERS
C
         CALL CHROMA(SPECB,SPECR)
         IF(BETA.EQ.0.) GO TO 40031
C
C     CORRECT BACKGROUND ATMOSPHERE OPTICAL DEPTH FOR NON-VERTICAL
C     VIEWING ANGLE.
C
         TAU=TATOIZ(19)/SIN(BETA*RAD)
         GO TO 40032
C
C     OPTICAL DEPTH FOR HORIZONTAL VIEW.
C
40031 TAU=TAUTOD(19)+TAUTDI(19)
40032 CONTINUE
         IF(IFLAGP.EQ.0) GO TO 40040
C        WRITE(6,40060) BETA,TAU,YCAP,VAL,X,Y,YCAPD,VALD,CONT1,CONT2,CONT3,
C       1BRATIO,XD,YD,DELUV,DELAB
         GO TO 40050
40040 CONTINUE
C***     WRITE(6,40070) THETA,BETA,TAU,YCAP,VAL,X,Y,YCAPD,VALD,CONT1,CONT2,
C***    1CONT3,BRATIO,XD,YD,DELUV,DELAB
         IFLAGP = 1
40050 CONTINUE
40060 FORMAT(5X,F5.0,3F8.2,2F8.4,2F8.2,8F8.4)
40070 FORMAT(/,2F5.0,3F8.2,2F8.4,2F8.2,8F8.4)
40100 CONTINUE
         IFLAGQ=1
C
C     LOOP FOR 6 PLUME-BASED SCATTERING ANGLES
C
         DO 40200 I=1,6
         IF(IFLAGQ.LT.0) GO TO 40131
```

```
C ***********************************************************************

C***  WRITE(6,40010)
C***  WRITE(6,40120)
C***  WRITE(6,40130)
40120 FORMAT(5X,61H''' WHITE, GRAY, AND BLACK OBJECTS AT INDICATED DISTA
     1NCES ***,//)
40130 FORMAT(6H THETA,2X,5HRO/RV,1X,7HREFLECT,4X,4HYCAP,7X,1HL,7X,1HX,7X
     1,1HY,8H DELYCAP,4X,4HDELL,2X,6HC(400),2X,6HC(550),2X,6HC(700),2X,6
     1HBRATIO,4X,4HDELX,4X,4HDELY,2X,6HE(LUV),2X,6HE(LAB))
40131 CONTINUE
      IFLAGQ=-1*IFLAGQ
C
C    ASSIGN SCATTERING ANGLE
C
      ITHETA=I+1
      THETA=TT(ITHETA)
      IFLAGP=0
C
C    CALCULATE BACKGROUND ATMOSPHERE INTENSITIES WITHOUT PLUME
C
      CALL BACCLN(ZENITH, 0., THETA,ITHETA, SPECB)
C
C    LOOP FOR DIFFERENT SHADES OF BACKGROUND OBJECTS.
C
      DO 40200 K=1,3
C
C    K = 1 FOR WHITE OBJECTS, 2 FOR GRAY, 3 FOR BLACK
C
      XLUMIN=REFL(K)/(2.*PI)
      DO 40200 J=1,7
C
C    LOOP FOR 7 PLUME-BASED BACKGROUND OBJECT DISTANCES AS FUNCTION
C    OF AMBIENT VISUAL RANGE.
C
      RO=ROBJ(J)*RVAMB
C
C    CALCULATE INTENSITIES FOR BACKGROUND OBJECT WITHOUT PLUME.
C
      CALL BACOBJ(ZENITH,BETA,THETA,ITHETA,RO,SPECB,XLUMIN)
C
C    CALCULATE DIFFERENCE IN COLOR OF OBJECTS VIEWED THROUGH
C    THE BACKGROUND ATMOSPHERE COMPARED WITH THAT VIEWED
C    THROUGH A RAYLEIGH ATMOSPHERE.
C
      CALL CHROMA(SPECB,SPECR)
      IF(IFLAGP.EQ.1) GO TO 40140
C     WRITE(6,40160) THETA, ROBJ(J),REFL(K),YCAP,VAL,X,Y,YCAPD,VALD,
C    1CONT1,CONT2,CONT3,BRATIO,XD,YD,DELUV,DELAB
      IFLAGP = 1
      GO TO 40150
40140 CONTINUE
C***  WRITE(6,40170) ROBJ(J),REFL(K),YCAP,VAL,X,Y,YCAPD,VALD,CONT1,CONT2
C*** 1,CONT3,BRATIO,XD,YD,DELUV,DELAB
40150 CONTINUE
40160 FORMAT(/,F5.0,4F8.2,2F8.4,2F8.2,8F8.4)
40170 FORMAT(5X,4F8.2,2F8.4,2F8.2,8F8.4)
44120 CONTINUE
40200 CONTINUE
C
```

```
C ***********************************************************************


C   CONVERSION FACTOR FROM G/S TO MICRO-G/SEC AT REFERENCE CONDITIONS (1
C   ATMOSPHERE) .  FOR ONE STACK INSTEAD OF TOTAL STACK EMISSIONS.
C
       C2 = ((1.E6/UNITS)/PAMB)*(PGTEMP/298.)
C
C CONVERT G/S TO PPM-CU M/S FOR GASES AND TO MICRO-G/CU M - CU M/S FOR
C     PARTICULATES.
       QSO2  = QSO2*C2* 3.821E-4
       QNOX  = QNOX*C2* 5.315E-4
       QPART = QPART*C2
       QO2   = FGO2*1.E4*FLOW
       PI = 3.14159
       IF(IDILU .EQ.0)GO TO 45
       WRITE(6,10)
       WRITE (6,41) (PLANT(J),J=1,6)
41     FORMAT (35X,62HINITIAL PLUME RISE AND DILUTION AND NITROGEN DIOXID
     1E FORMATION//45X,6A4//2X,4HTIME,5X,1HX,5X,7HDELTA H,4X,1HU,7X,1HW,
     17X,1HV,4X,5HSIGMA,4X,4HTEMP,5X,2HO2,4X,12HNO2-NO RATIO,5X,3HNOX,
     16X,2HNO,5X,4HNO2T,4X,3HSO2,3X,11HPARTICULATE/2X,5H(SEC),3X,3H(M),
     15X,3H(M),5X,5H(M/S),3X,5H(M/S),3X,5H(M/S),3X,3H(M),5X,3H(K),4X,
     15HMOL P,3X,5HEQUIL,3X,6HACTUAL,2X,5H(PPM),4X,5H(PPM),2X,5H(PPM),
     13X,5H(PPM),3X,5HUG/M3/)
42     FORMAT (F7.0,2F8.1,3F8.2,3F8.1,1P2E8.1,0P4F8.3,1PE10.2)
C
C CALCULATE THE INTEGER CLOSEST TO THE NO.OF SECONDS AFTER EMISSION FROM
C      THAT PLUME IS TRANSPORTED 1 KM
C
45     NSECP=1000./U
C
4300   CONTINUE
C
C
C
C DO LOOP LAGRANGIAN FRAME OF REFERENCE (EVERY 10 SECONDS)
C
       NSECP1=NSECP+1
       DO 50 NSEC = 1,NSECP1,10
       T = NSEC-1
       IF(T.EQ.0.0) GO TO 43
C
C CALCULATION OF PARCEL VELOCITY, POSITION,DILUTION FACTOR
C
C     POWER LAW RISE OF PLUME TO EFFECTIVE STACK HEIGHT.
C
C
C     CHANGE FOR F = 0.0
C
       IF(XFINAL.EQ.0.0)GO TO 92
       DELH=RISE*(U*T/XFINAL)**.66667
       GO TO 93
92     DELH=0.0
93     CONTINUE
C
C     CORRECT DELH IF U*T > XFINAL
C
       IF(DELH.GT.RISE) DELH=RISE
C
C     CALCULATE VERTICAL VELOCITY VIA POWER LAW
```

```
C ***************************************************************************


C
      W=.66667*RISE*FLOAT(NSECF)**(-0.66667)*FLOAT(NSEC)**(-.33333)
C
C    W =WMAX AT STACK, W = 0 AT XFINAL
C
      IF(NSEC.GT.NSECF) W=0.
      IF (W.GT.WMAX) W=WMAX
C
C    VELOCITY VECTOR AT NSEC.
C
      V = SQRT(U**2.+W**2.)
      DENOM = DELH**2*V*(1.57/2.15)/2.15
      IF (DENOM.LT.FLOW) DENOM=FLOW
      GO TO 44
C
C PROPERTIES AT TOP OF STACK
C
43    DELH = 0.0
      W = WMAX
      DENOM = FLOW
      V = W
C
C CALCULATION OF PLUME TEMPERATURE
C
44    TEMP = TAMB*DENOM/(DENOM-FLOW*(1.-(TAMB/FGTEMP)))
C
C DOWNWIND DISTANCE FROM STACK IN METERS
C
      XM = U*T
C
C HORIZONTAL OR VERTICAL DISPERSION COEFFICIENT = 1/2.15 OF PLUME
C RADIUS.  RADIUS = 1/2 OF PLUME RISE.
C
      SIG = (DELH/2.)/2.15
C
C O2 CONCENTRATION IN PPM IN PLUME IS NEEDED TO CALCULATE NO2 FORMATION
C
      XO2 = 209460. + (QO2 - FLOW*209460.)*TEMP/(DENOM*FGTEMP)
C
C O2 IN MOL PERCENT
C
      PO2 = XO2*1.E-4
C
C CALCULATION OF EQUILIBRIUM NO2/NO RATIO
C
      C3 = 16.786 + (8.841 - 16.786)*(TEMP-298.)/(500.-298.)
      RATIOE = SQRT(10.**C3*4.09E-11*XO2)
C
C ACTUAL NO2/NO RATIO. INITIALLY = EQUILIBRIUM. NEVER GREATER THAN EQUIL
C
      IF(T.EQ.0.0) RATIOA= 8.03E-12*EXP(526.4/FGTEMP)*QNOX/FLOW
     1                    *XO2*HSTACK/W
      IF(RATIOA.GT.RATIOE) RATIOA = RATIOE
C
C POLLUTANT CONCENTRATIONS. NO2 RESULTING FROM TERMOLECULAR REACTION ONLY
C
      XNOX = QNOX*TEMP/(DENOM*FGTEMP)
      XSO2 = QSO2*TEMP/(DENOM*FGTEMP)
```

```
C **********************************************************************

      XPART = QPART*TEMP/(DENOM*PGTEMP)
      XNO = XNOX/(1.+RATIOA)
      XNO2T = XNO*RATIOA
      IF(IDILU .EQ. 0)GO TO 50
      WRITE (6,42) T,XM,DELH,U,W,V,SIG,TEMP,PO2,RATIOE,RATIOA,XNOX,XNO,
     1             XNO2T,XSO2,XPART
C
C CALCULATION OF CHANGE IN NO2/NO RATIO VIA TERMOLECULAR REACTION IN 10
C
50    RATIOA=RATIOA+4.015E-12*EXP(1046./(1.987*TEMP))*XNO*XO2*10.
C
C EMISSION RATES PER STACK ARE CONVERTED BACK TO TOTALS.
C
      QSO2 = QSO2*UNITS
      QNOX = QNOX*UNITS
      QPART = QPART*UNITS
C
C   CALCULATION OF VIRTUAL POINT SOURCE DISTANCE OFFSET
C   SO THAT CALCULATED SIGMA-X AND SIGMA-Y MATCH INITIAL
C   PLUME DILUTION RESULTS AT  1 KILOMETER.
C
C  IS = STABILITY CLASS
C
C
      I=IS
      IF(IDIS.EQ.9)GO TO 476
      DILUTE=((RISE*RISE/4.)/2.15)/2.15
      XM=XFINAL
      SIGYXZ=0.
470   CONTINUE
      IF(IDIS.EQ.1) GO TO 471
      SY=SYPAS(I,XM)
      SZ=SZPAS(I,XM)
      GO TO 472
471   SY=SYTVA(I,XM)
      SZ=SZTVA(I,XM)
472   SIGYZI=SIGYXZ
      SIGYXZ=SY*SZ
      IF(DILUTE.LE.SIGYXZ.AND.SIGYZI.EQ.0.)GO TO 476
      IF(DILUTE.LE.SIGYXZ)GO TO 475
      XM=XM+1.E4
      GO TO 470
475   XVIRTL=XM-XFINAL-1.E4+1.E4*(DILUTE-SIGYZI)/(SIGYXZ-SIGYZI)
      GO TO 477
476   XVIRTL=0.
477   CONTINUE
C  CALCULATE PHOTOLYSIS RATE CONSTANTS FOR EACH OF 24 HOURLY PERIODS IN A
C  DAY.
C    CONVERT STACK UTM COORDINATES TO LATITUDE AND LONGITUDE.
C
      CALL MAPUTG(XSTACK,YSTACK,IZONE,ALON,ALAT)
      DO 49 I=1,24
C
C    TIMER = HOURS OF DAY (MILITARY CLOCK)
C
      TIMER=FLOAT(I)*100.
C
C    CALCULATE SUN ELEVATION ANGLE
```

```
C ***********************************************************************

C
      CALL SOLARZ(ALAT,ALON,TZONE,IYEAR,IMO,IDAY,TIMER,SUNELE,5)
      AZEN=90.-SUNELE
      IF(AZEN.GT.90.)AZEN=90.
      PHIKRR(I)=0.0
      QJ(I)=0.0
      IF(AZEN.EQ.90.)GO TO 48
C
C   DYNAMIC EQUILIBRIUM CONSTANT (NO2 AND NO)
C
      PHIKRR(I)=(1.E-2/0.44)*EXP(-0.38/COS(AZEN*RAD))
C
C   OZONE PHOTOLYSIS RATE CONSTANT
C
      QJ(I)=2.23E-5*60.*(COS(AZEN*RAD))**2.74
   48 CONTINUE
   49 CONTINUE
C
C ***********************************************************************
C
C DO LOOP FOR POLLUTANT CONCENTRATIONS AND VISUAL EFFECTS AT 16 DOWNWIND
C DISTANCES
C
C ***********************************************************************
C
      NZFLAG=0
C
C   INITIALIZE EFFECTIVE EMISSION RATES FOR SO2, NOX, SO4, NO3, AND
C  PRIMARY PARTICULATE, AND CONVERSION RATES FOR SO2, NOX, AND NO2.
C
      DO 495 NZ=1,6
      DO 495 NT=NX1,NX2
      QSO2TR(NZ,NT)=QSO2
      QNOXTR(NZ,NT)=QNOX
      QSO4TR(NZ,NT)=0.
      QNO3TR(NZ,NT)=0.
      QPARTT(NZ,NT)=QPART
      RSO2R(1,NZ,NT)=RSO2(1)
      RNOXR(1,NZ,NT)=0.
      RNO2X(1,NZ,NT)=0.
C
C   SET NO2/NO RATIO TO INITIAL VALUE CALCULATED EARLIER. SET TO ZERO
C   AT SURFACE.
C
      RATIOT(NZ,NT)=RATIOA
      IF(NZ.EQ.6)RATIOT(NZ,NT)=0.
  495 CONTINUE
      CHIQTY(6)=0.
      QPARTO=QPART
C
C   INITIALIZE VALUE FOR DOWNWIND DISTANCE OF PREVIOUS POINT.
C
      XM=0.
C
C   INITIALIZE TOTAL DEPOSITION FOR SO2, NOX, PRIMARY PARTICULATE,
C   SULFATE AND NITRATE.
C
      TDSO2=0.
```

```
C ***********************************************************************

      TDNOX=0.
      TDPART=0.
      TDSO4=0.
      TDNO3=0.
C
C    *****LOOP ON DOWNWIND DISTANCE *******
C
      DO 1000 NX = NX1,NX2
C
C    XM0 = DOWNWIND DISTANCE OF PREVIOUS POINT.
C
      XM0=XM
C
C    XM = DOWNWIND DISTANCE (METERS)
C
      XM=DIST(NX)
C
C    XKM = DOWNWIND DISTANCE (KILOMETERS)
C
      XKM=XM/1000.
C
C   ADD IN VIRTUAL POINT SOURCE OFFSET TO ACCOUNT FOR INITIAL DILUTION
C   DURING PLUME RISE.
C
      XADD=XM+XVIRTL
C
C    IS = STABILITY
C
      I = IS
C
C   NXSTAB = DOWNWIND DISTANCE INDEX FOR DISTANCE WHERE STABILITY CHANGES
C
      IF(NX.GT.NXSTAB)GO TO 135
      IF(IDIS.NE.9) GO TO 510
C
C    IDIS = 9 FOR READING IN SPECIAL SIGMA VALUES FOR EACH DOWNWIND
C    DISTANCE
C
      READ(5,5) SY,SZ
      GO TO 136
  510 CONTINUE
      IF(IDIS.EQ.1) GO TO 511
C
C    PASQUILL-GIFFORD SIGMAS (I=1 FOR "A", 2 FOR "B", 3 FOR "C", ETC)
C
      SY=SYPAS(I,XADD)+(YINITL/2.)/PI
      SZ=SZPAS(I,XADD)+(ZINITL/2.)/PI
      GO TO 512
C
C    TVA SIGMAS
C
  511 SY=SYTVA(I,XADD)+(YINITL/2.)/PI
      SZ=SZTVA(I,XADD)+(ZINITL/2.)/PI
  512 CONTINUE
C
C    IF UPWIND OF STABILITY CHANGE, JUMP AROUND
C
      IF(NX.LT.NXSTAB)GO TO 136
```

```
C **********************************************************************

C
C   NXSTAB=DOWNWIND DISTANCE INDEX WHERE STABILITY CHANGES
C    NXSTAB MUST BE GREATER THAN 1
C   I=STABILITY INDEX FOR FIRST PART OF PLUME.
C   INEW=NEW STABILITY INDEX
C   SYNEW=SIGMA-Y FOR NEW STABILITY.
C   SZNEW=SIGMA-Z FOR NEW STABILITY.
C   CODE FOR NEW STABILITY.  FIRST DETERMINE VIRTUAL DOWNWIND
C   DISTANCE FOR NEW STABILITY TO AVOID LARGE PLUME DIMENSIONAL
C   DISCONTINUITY AT STABILITY INTERFACE.
C
  100   CONTINUE
        IF(IDIS.EQ.1)GO TO 101
        DISTA=5000.
        SYNEW=SYPAS(INEW,DISTA)
        DELSIG=SYNEW-SY
C
C    FIND VIRTUAL DISTANCE FOR NEW STABILITY WHERE DIFFERENCE IN
C    SIGMA-Y FOR INITIAL STABILITY AND SIGMA-Y AT NEW STABILITY
C    STOPS DECREASING AND STARTS INCREASING, WITH A DISTANCE
C    INTERVAL OF 1 KM. ASSUME SYNEW IS FIRST LESS THAN SY, THEN AT SOME
C    DISTANCE GOES THROUGH ZERO AND STARTS INCREASING.
C
  140   DISTB=DISTA
        DISTA=DISTA+5000.
        SYNEW=SYPAS(INEW,DISTA)
        DELSG=SYNEW-SY
        IF(ABS(DELSG).GT.ABS(DELSIG))GO TO 141
        DELSIG=DELSG
        GO TO 140
  141   CONTINUE
C
C    VIRTUAL DISTANCE FOR NEW STABILITY FOR SIGMA-Y IS BETWEEN
C    DISTB AND DISTA.
C   CALCULATE DISTANCE OFFSET FOR FUTURE SY DETERMINATIONS.
C
        DDISTY=DISTB+5000.*((0.-DELSIG)/(DELSG-DELSIG))-DIST(NX)
C
C    SAME PROCEDURE FOR SIGMA-Z
C
        DISTA=5000.
        SZNEW=SZPAS(INEW,DISTA)
        DELSIG=SZNEW-SZ
  142   DISTB=DISTA
        DISTA=DISTA+5000.
        SZNEW=SZPAS(INEW,DISTA)
        DELSG=SZNEW-SZ
        IF(ABS(DELSG).GT.ABS(DELSIG))GO TO 143
        DELSIG=DELSG
        GO TO 142
  143   CONTINUE
        DDISTZ=DISTB+5000.*((0.-DELSIG)/(DELSG-DELSIG))-DIST(NX)
        SY=SYNEW
        SZ=SZNEW
        GO TO 136
C
C   SAME PROCEDURE FOR TVA SIGMA-Y
C
```

```
C **********************************************************************

 101   DISTA=5000.
       SYNEW=SYTVA(INEW,DISTA)
       DELSIG=SYNEW-SY
 144   DISTB=DISTA
       DISTA=DISTA+5000.
       SYNEW=SYTVA(INEW,DISTA)
       DELSG=SYNEW-SY
       IF(ABS(DELSG).GT.ABS(DELSIG))GO TO 145
       DELSIG=DELSG
       GO TO 144
 145   CONTINUE
       DDISTY=DISTB+5000.*((0.-DELSIG)/(DELSG-DELSIG))-DIST(NX)
 C
 C    SAME PROCEDURE FOR TVA SIGMA-Z
 C
       DISTA=5000.
       SZNEW=SZTVA(INEW,DISTA)
       DELSIG=SZNEW-SZ
 146   DISTB=DISTA
       DISTA=DISTA+5000.
       SZNEW=SZTVA(INEW,DISTA)
       DELSG=SZNEW-SZ
       IF(ABS(DELSG).GT.ABS(DELSIG))GO TO 147
       DELSIG=DELSG
       GO TO 146
 147   CONTINUE
       DDISTZ=DISTB+5000.*((0.-DELSIG)/(DELSG-DELSIG))-DIST(NX)
 135   IF(NX.LE.NXSTAB)GO TO 136
 C
 C    CODE  FOR CALCULATING SIGMA-Y AND SIGMA-Z DOWNWIND
 C    OF STABILITY CHANGE.
 C    FIRST ADD DISTANCE OFFSET FOR NEW STABILITY BEFORE
 C    CALCULATING SY AND SZ
 C
       XMY=DIST(NX)+DDISTY
       XMZ=DIST(NX)+DDISTZ
       IF(IDIS.EQ.1)GO TO 122
       SY=SYPAS(INEW,XMY)
       SZ=SZPAS(INEW,XMZ)
       GO TO 136
 122   SY=SYTVA(INEW,XMY)
       SZ=SZTVA(INEW,XMZ)
 136   CONTINUE
       WRITE (6,10)
       WRITE (6,51) (PLANT(J),J=1,6)
 51    FORMAT (25X,50HCONCENTRATIONS OF AEROSOL AND GASES CONTRIBUTED BY,
      1        //35X,6A4/)
       WRITE (6,52) XKM
 52    FORMAT(25H DOWNWIND DISTANCE (KM) =, F7.1)
       WRITE (6,53) H
 53    FORMAT(19H PLUME ALTITUDE (M) ,5X,1H=,F7.0)
       WRITE (6,54) SY
 54    FORMAT(12H SIGMA Y (M),12X,1H=,F7.0)
       WRITE (6,55) SZ
 55    FORMAT(12H SIGMA Z (M),12X,1H=,F7.0)
       WRITE(6,56) RSO2R(NX,3,NX)
  56   FORMAT(27H SO2-SO4 CONVERSION RATE=  ,F10.4,11H PERCENT/HR)
       WRITE(6,57) RNOXR(NX,3,NX)
```

```
C ************************************************************************

   57 FORMAT(27H NOX-NO3 CONVERSION RATE=  ,F10.4,11H PERCENT/HR)
      WRITE(6,271)
      IFLAGP=0
C
C CALCULATE DECREASE OF SO2 AND NOX FLUX AND INCREASE IN PARTICULATE
C FLUX  DUE TO SULFATE AND NITRATE FORMATION.
C ALSO, CALCULATE THE DECREASE IN FLUX DUE TO SURFACE DEPOSITION.
C
      NTT=0
C   TIME IN HOURS AND DECIMAL FRACTION OF HOUR
      TIMEHR=AINT(TIME/100.)+AMOD(TIME,100.)/60.
C
C    CHECK IF FIRST DOWNWIND POINT
C
      IF(NX.EQ.NX1)GO TO 68
C
C    TIME IN HOURS FOR TRANSPORT FROM PREVIOUS (NX-1) DOWNWIND POINT
C
      DTIME=((DIST(NX)-DIST(NX-1))/U)/3600.
      GO TO 69
   68 DTIME=0.
C
C    TIME AT PREVIOUS DOWNWIND POINT
C
   69 TIMER=TIMEHR-DTIME
C
C    NTT STOPS SURFACE DEPOSITION AT NIGHT
C
      IF(TIMER.LT.7..OR.TIMER.GT.18.)NTT=1
C
C    CALCULATION OF DEPOSITION
C
      YGRND=CHIQTY(6)*1000.
      DEPOT=YGRND*(XM-XM0)
C
C   SUPPRESS SURFACE DEPOSITION AT NIGHT (ASSUME STABLE STRATIFICATION)
C    DEPOSITION OF PRIMARY PARTICULATE
C
      DEPPAR=QPART*VDCOR*DEPOT*FLOAT(1-NTT)/100.
C
C   ADJUST EFFECTIVE PARTICULATE EMISSION RATE FOR DEPOSITION
C
      QPART=QPART-DEPPAR
C
C    LOOP ON DOWNWIND DISTANCES FROM PRESENT POSITION (DIST(NX)) TO
C    FINAL POINT (DIST(NX2)).
C
      DO 570 NT=NX,NX2
C
C    CALCULATE DEPOSITION FOR SO2, NOX, SO4, AND NO3
C
      DEPSO2=QSO2TR(6,NT)*VDSO2*DEPOT*FLOAT(1-NTT)/100.
      DEPNOX=QNOXTR(6,NT)*VDNOX*DEPOT*FLOAT(1-NTT)/100.
      DEPSO4=QSO4TR(6,NT)*VDSUB*DEPOT*FLOAT(1-NTT)/100.
      DEPNO3=QNO3TR(6,NT)*VDNOX*DEPOT*FLOAT(1-NTT)/100.
C
C    LOOP ON ALTITUDE
C
```

```
C ***********************************************************************

        DO 568 NZ=1,6
        FORSO2=((QSO2TR(NZ,NT)*RSO2R(NX,NZ,NT)/3.6E5)/U)*(XM-XM0)
        FORNOX=((QNOXTR(NZ,NT)*RNOXR(NX,NZ,NT)/3.6E5)/U)*(XM-XM0)
       1 *RNO2X(NX,NZ,NT)
 C
 C    ADJUST EFFECTIVE SO2 AND NOX EMISSION RATES FOR CONVERSION TO
 C    SECONDARY SPECIES AND FOR SURFACE DEPOSITION AFTER TRANSPORT
 C    FROM DIST(NX-1) TO DIST(NX).
 C
        QSO2TR(NZ,NT)=QSO2TR(NZ,NT)-FORSO2-DEPSO2
        QNOXTR(NZ,NT)=QNOXTR(NZ,NT)-FORNOX-DEPNOX
 C
 C    ADJUST EFFECTIVE SULFATE EMISSION RATE, INCLUDING SULFATE
 C    FORMATION AND SURFACE DEPOSITION.  (ADJUST MASS FLUX)
 C
        QSO4TR(NZ,NT)=QSO4TR(NZ,NT)
       1  +1.5/3.821E-4*FORSO2-DEPSO4
 C
 C  ADJUST NO3 MASS FLUX
 C
        QNO3TR(NZ,NT)=QNO3TR(NZ,NT)+FORNOX-DEPNO3
 C
 C     ADJUST PARTICULATE MASS FLUX FOR SULFATE FORMATION
 C
        QPARTT(NZ,NT)=QPART+QSO4TR(NZ,NT)
 568    CONTINUE
        IF(NT.NE.NX)GO TO 569
 C
 C    CALCULATE TOTAL DEPOSITION TO DIST(NX) FOR SO2, NOX, PARTICULATE,
 C    SO4, AND NO3.
 C
        TDSO2=TDSO2+DEPSO2
        TDNOX=TDNOX+DEPNOX
        TDPART=TDPART+DEPPAR
        TDSO4=TDSO4+DEPSO4
        TDNO3=TDNO3+DEPNO3
 C
 C    CALCULATE RATIO OF TOTAL DEPOSITION TO EMISSION RATE
 C
        FDSO2=TDSO2/QSO2
        FDNOX=TDNOX/QNOX
        FDPART=TDPART/QPART0
        FDSO4=((TDSO4/QSO2)/1.5)*3.821E-4
        FDNO3=((TDNO3/QNOX)/1.35)*5.315E-4
 569    CONTINUE
 570    CONTINUE
 C
 C DO LOOP FOR 6 ALTITUDES:  2*SIGMA-Z+H, SIGMA-Z+H, H, H -SIGMA-Z
 C    H -2*SIGMA-Z, SURFACE
 C
        DO 60 NZ = 1,6
        RNZ = NZ
        IF(NZ.EQ.6) GO TO 58
        Z = H + (3.-RNZ)*SZ
        IF(Z.LT.0.) Z=0.
        GO TO 59
 58     Z = 0.0
  59    CONTINUE
```

```
C ************************************************************************

C
C     GAUSSIAN DIFFUSION CALCULATION
C
       ARG1 = -0.5*(H+Z)*(H+Z)/SZ/SZ
       ARG2 = -0.5*(H-Z)*(H-Z)/SZ/SZ
C
C     PREVENTION OF EXPONENTIAL UNDERFLOW
C
       IF(ARG1.LT.(-290.)) ARG1=-290.
       IF(ARG2.LT.(-290.)) ARG2=-290.
       CHIQ=((TAMB/FGTEMP)/(2.*PI*SY*SZ*U))*(EXP(ARG1)+EXP(ARG2))
       IF(CHIQ.LT.2.E-30)CHIQ=2.E-30
C
C     CHECK IF EQUILIBRIUM PLUME CENTERLINE HEIGHT IS ABOVE THE TOP
C     OF THE MIXED LAYER.
C
       IF(H.GT.HPBLM) GO TO 594
C
C     VIRTUAL SOURCE TO ACCOUNT FOR REFLECTION OFF CAPPING LAYER.
C
       HPRIME=2.*HPBLM-H
C
C     IF Z IS GTR THAN TOP OF MIXED LAYER, CHANGE Z TO TOP OF MIXED
C     LAYER.
C
       IF(Z.GT.HPBLM) Z=HPBLM
C
C     REVISED CALCULATION FOR PLUME BELOW INVERSION.
C
       ARG1 = -0.5*(H+Z)*(H+Z)/SZ/SZ
       ARG2 = -0.5*(H-Z)*(H-Z)/SZ/SZ
       ARG3=-0.5*(HPRIME-Z)*(HPRIME-Z)/SZ/SZ
       ARG4=-0.5*(HPRIME+Z)*(HPRIME+Z)/SZ/SZ
       IF(ARG3.LT. -290. ) ARG3=-290.
       IF(ARG4.LT. -290. ) ARG4=-290.
       CHIQ=(TAMB/FGTEMP)/(2.*PI*SY*SZ*U)*(EXP(ARG1)+EXP(ARG2)+EXP(ARG3)
      1 + EXP(ARG4))
       IF(CHIQ.LT.2.E-30)CHIQ=2.E-30
C
C     FORMULA FOR UNIFORMLY MIXED CHI/Q.  CONCENTRATION CONSTANT IN Z
C     FROM SURFACE TO INVERSION.
       CHIQ1=(TAMB/FGTEMP)/(SQRT(2.*PI)*SY*HPBLM*U)
C
C     BRANCH IF Z = PLUME CENTERLINE HEIGHT.
C
       IF(NZ.EQ.3) GO TO 592
       IF(NZFLAG.EQ.1) CHIQ=CHIQ1
       GO TO 594
C
C      IF GAUSSIAN PLUME CENTERLINE CHI/Q < CHI/Q FOR UNIFORMLY MIXED
C      CASE, SET FLAG TO USE CHI/Q FOR UNIFORMLY MIXED CASE.
C
   592 IF(CHIQ.LT.CHIQ1) NZFLAG=1
       IF(NZFLAG.EQ.1) CHIQ=CHIQ1
   594 CONTINUE
C
C     BRANCH FOR FIRST DOWNWIND DISTANCE
C
```

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C ************************************************************************

      IF(NX.EQ.1) GO TO 596
C
C     MAXIMUM CHI/Q CANNOT EXCEED CHI/Q FOR CENTERLINE AT PREVIOUS
C     DOWNWIND POINT
C
      XQMAX=XQ(3)
      IF(CHIQ.GT.XQMAX) CHIQ=XQMAX
  596 CONTINUE
C
C     SAVE CHI/Q VALUES FOR ALL 6 LEVELS.
C
      XQ(NZ)=CHIQ
      CHIQIY(NZ)=CHIQ*SQRT(2.*PI)*SY
      CHIQIY(NZ)=CHIQIY(NZ)/1000.
C
C     OH MODEL FOR SULFATE AND NITRATE FORMATION.  CALCULATE CONVERSION
C     FOR PLUME PARCEL AT PRESENT POSITION AS IT IS ADVECTED TO POINTS
C     FARTHER DOWNWIND WHERE CONCENTRATIONS ARE CALCULATED.
C   CALCULATE PLUME PARCEL CONCENTRATIONS CORRESPONDING TO THE PLUME
C   PARCEL AT DOWNWIND DISTANCE NX WHICH  GETS TRANSPORTED TO
C   DOWNWIND DISTANCE I. SO4 AND NO3 FORMATION RATES ARE CALCULATED FOR
C   THE TIME CORRESPONDING TO PARCEL DISTANCE I.
C
C     TIME IN HOURS AND DECIMAL FRACTIONS
C
      TIMEHR=AINT(TIME/100.)+AMOD(TIME,100.)/60.
      DO 5960 I=NX,NX2
C
C     TIME FOR TRANSPORT FROM PRESENT POSITION TO POINT DOWNWIND (DIST(I))
C
      DTIME=((DIST(I)-DIST(NX))/U)/3600.
C
C     CALCULATE TIME OF DAY PARCEL WOULD BE AT PRESENT POINT (DIST(NX))
C     IN ORDER TO BE TRANSPORTED  TO EACH POINT FARTHER DOWNWIND FOR
C     TIME OF OPTICS CALCULATIONS.
C
      TIMER=TIMEHR-DTIME
 5961 IF(TIMER.GT.0.)GO TO 5962
C
C     CORRECT FOR NEGATIIVE CLOCK TIME
C
      TIMER=TIMER+24.
      GO TO 5961
 5962 CONTINUE
C
C     IT1 = HOUR OF DAY FOR PARCEL AT DIST(NX)
C
      IT1=INT(TIMER)
      IF(IT1.EQ.0)IT1=24
      IT2=IT1+1
      IF(IT2.EQ.25)IT2=1
C
C     RTIME = DECIMAL FRACTION OF TIME OF DAY (TIME BEYOND IT1)
C
      RTIME=AMOD(TIMER,1.)
C
C     LINEAR INTERPOLATION OF NO2 - NO DYNAMIC EQUILIBRIUM CONSTANT
C     AND INTERPOLATION OF PHOTOLYSIS RATE CONSTANT FOR TIME OF DAY
```

```
C ***********************************************************************
C
C    WHEN PLUME PARCEL WOULD BE AT DIST(NX) AND BE TRANSPORTED TO
C    TO DIST(NX+1), DIST(NX+2), ETC.
C
      PHIKKA=PHIKKR(IT1)+RTIME*(PHIKKR(IT2)-PHIKKR(IT1))
      QJA=QJ(IT1)+RTIME*(QJ(IT2)-QJ(IT1))
C
C    CONCENTRATION OF SO2
C
      XSO2R=QSO2TR(NZ,I)*CHIQ
C
C    CONCENTRATION OF NOX
C
      XNOXR=QNOXTR(NZ,I)*CHIQ
C
C    CONCENTRATION OF NO2
C
      XNO2TR=XNOXR*RATIOT(NZ,I)/(1.+RATIOT(NZ,I))
      SUMR=XNOXR+AMBNOX+O3AMB+XNO2TR+AMBNO2+PHIKKA
      XNO2R=0.5*(SUMR-SQRT(ABS(SUMR*SUMR-4.*(XNOXR+AMBNOX)*
     1 (O3AMB+XNO2TR+AMBNO2))))
C
C    NOX PLUME CONCENTRATION WITH AMBIENT BACKGROUND NOX ADDED.
C
      TOTR=XNOXR+AMBNOX
      IF(XNO2R.GT.TOTR)XNO2R=TOTR
      IF(NX.EQ.NX2)GO TO 39
      RATIOT(NZ,I)=RATIOT(NZ,I)+4.015E-12*EXP(1046./(1.987*TAMB))*
     1 (TOTR-XNO2R)*209460.*(DIST(NX+1)-DIST(NX))/U
 39   CONTINUE
C
C    OZONE CALCULATION
C
      XO3R=O3AMB-(XNO2R-XNO2TR-AMBNO2)
C
C    OH RADICAL CONCENTRATION
C
      XOHR=2.*QJA*3.4E5*WATER*XO3R/((4.45E10+3.4E5*WATER)*
     1 (2000.*XSO2R+14.E3*XNO2R))
C
C    MAXIMUM OH RADICAL CONCENTRATION
C
      XOHRMX=4.87E-7*QJA/1.32E-3
      IF(XOHR.GT.XOHRMX)XOHR=XOHRMX
C
C    SO2, NOX, AND NO2  CONVERSION RATES
C
      RSO2R(NX+1,NZ,I+1)=2000.*XOHR*60.*100.+RSO2(NX+1)
      RNOXR(NX+1,NZ,I+1)=14.E3*XOHR*60.*100.
      RNO2X(NX+1,NZ,I+1)=XNO2R/TOTR
C
C    BRANCH IF PLUME PARCEL NOT AT FINAL POSITION (I=NX)
C
      IF(I.NE.NX)GO TO 5959
C
C    SAVE SO2 CONCENTRATION AND PARTICULATE CONCENTRATION.
C
      XSO2=XSO2R
      XPART=QPART*CHIQ
```

```
C ***********************************************************************
C
C     CALCULATE  MOLE RATIO OF SULFATE TO INITIAL SO2 (%).
C
        RATIOS= QSO4TR(NZ,I)/1.5 * 3.821E-4/QSO2*100.
C
C     SAVE OZONE, NOX, AND NO2 CONCENTRATIONS.
C
        XO3=XO3R
        XNOX=XNOXR
        XNO2=XNO2R
C
C     SAVE EFFECTIVE EMISSION RATE OF NO2 AND SO4 FOR LEVEL NZ
C
        QNO3=QNO3TR(NZ,I)
        QSO4=QSO4TR(NZ,I)
C
C    PERCENT NOX CONVERTED TO NO3 (NITRIC ACID VAPOR)
C
        RNO3=(QNO3/QNOX)*100.
C
C     TOTAL NOX CONCENTRATION
C
        TOT=TOTR
C
C     CALCULATE NO3 CONCENTRATION
C
        XNO3=QNO3*CHIQ
C
C     CALCULATE EFFECTIVE NO2 EMISSION RATE
C
        QNO2I(NZ)=XNO2R/CHIQ
        XNO2I(NX,NZ)=XNO2R
C
C    CALCULATE MOLE RATIO OF HNO3 TO INITIAL NOX(%).
C
        RATION=(QNO3TR(NZ,I)/QNOX)*100.
 5959 CONTINUE
 5960 CONTINUE
        IF(IFLAGP.EQ.1) GO TO 5616
C
C    WRITE OUT TITLES FOR PRINT FILE
C
        WRITE(6,5611)
 5611 FORMAT(9H ALTITUDE,9X,3HNOX,7X,3HNO2,7X,4HNO3-,2X,8HNO2/NTOT,2X,
     19HNO3-/NTOT,5X,3HSO2,7X,4HSO4=,2X,9HSO4=/STOT,5X,2HO3,5X,7HPRIMARY
     2,1X,9HBSP-TOTAL,2X,9HBSPSN/BSP)
        WRITE(6,5612)
 5612 FORMAT(16X,5H(PPM),5X,5H(PPM),5X,5H(PPM),2(2X,8H(MOLE %)),5X,
     15H(PPM),3X,7H(UG/M3),2X,8H(MOLE %),5X,5H(PPM),3X,7H(UG/M3),1X,10H(
     210-4 M-1),3X,3H(%),/)
 5616 CONTINUE
C
C    NO2 PLUME INCREMENT
C
        XNO2IN=XNO2-AMBNO2
        QNO2I(NZ)=XNO2IN/CHIQ
        XNO3=QNO3*CHIQ
C
```

```
C **********************************************************************


C  TOTAL NO3 (PLUME + AMBIENT)
C
      XNO3T=XNO3+AMBNO3
C
C  RATIO OF PLUME INCREMENT NO2 TO INITIAL NOX (%).
C
      RNO2=(100.*(XNO2-AMBNO2)/CHIQ)/QNOX
C
C  IF (PLUME NO2 - AMBIENT NO2) IS SMALL, RATIO SET TO ZERO.
C
      IF(XNO2IN.LT.0.0005)  RNO2 = 0.
C
C  MOLE RATIO OF TOTAL NO2 AND NO3 TO TOTAL NOX (PLUME + AMBIENT).
C
      RNO2T=(XNO2/(TOT+XNO3T))*100.
      RNO3T=(XNO3T/(TOT+XNO3T))*100.
C
C  TOTAL SO2 CONCENTRATION IN PLUME (PLUME + AMBIENT)
C
      XSO2T=XSO2+AMBSO2
C
C  SULFATE PLUME INCREMENT
C
      XSO4=QSO4*CHIQ
C
C  SAVE PARTICULATE AND SULFATE PLUME INCREMENTS FOR ALONG PLUME
C  OPTICAL ANALYSIS.
C
      XPARTP(NX,NZ)=XPART
      XPARTS(NX,NZ)=XSO4
C
C  TOTAL SULFATE CONCENTRATION.
C
      XSO4T=XSO4+AMBSO4
C
C  RATIO OF TOTAL SO4 COMPONENT TO TOTAL SULFUR COMPONENT.
C
      RSO4T=(XSO4T*3.821E-4/1.5)/(XSO2T+XSO4T*3.821E-4/1.5)
C
C  CONVERT TO PERCENT
C
      RSO4T=RSO4T*100.
C
C  PLUME INCREMENT OF OZONE (THIS IS LESS THAN ZERO FOR NOX PLUMES).
C
      XO3IN=XO3-O3AMB
C
C  TOTAL AEROSOL CONCENTRATION (PLUME PLUS BACKGROUND)
C
      XPT = XPART + CORAMB + AMBSO4
C
C  EXTINCTION COEFFICIENT FOR PLUME PRIMARY PARTICULATE AND
C  SULFATE AND CONVERT FROM 1/KM TO 1/METERS
C
      BSP=10.*(BTAPRM(19)*XPART+BTASO4(19)*XSO4)
C
C  ADD IN BACKGROUND AEROSOL EXTINCTION
C
```

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C ***************************************************************************

      BSPT=BSP+10.*BTAAER(19)
C
C  RATIO OF SULFATE EXTINCTION COEFFICIENT IN PLUME TO TOTAL
C  PLUME AEROSOL EXTINCTION COEFFICIENT (%).
C
      RSEC=1000.*BTASO4(19)*XSO4/BSP
C
C  RATIO OF PLUME SULFATE EXTINCTION COEFFICIENT TO TOTAL
C  AEROSOL EXTINCTION COEFFICIENT (%).
C
      RSECT=1000.*BTASO4(19)*XSO4T/BSPT
      WRITE(6,5613) ALT(NZ)
      WRITE(6,5614) XNOX,XNO2IN,XNO3,RNO2,RATION,XSO2,XSO4,RATIOS,
     1XO3IN,XPART,BSP,RSEC
 5613 FORMAT(2X,A4)
 5614 FORMAT(11H INCREMENT!,12F10.3)
      WRITE(6,5615) TOT,XNO2,XNO3T,RNO2T,RNO3T,XSO2T,XSO4T,RSO4T,XO3,
     1XPT,BSPT,RSECT
      IFLAGP=1
 5615 FORMAT(11H TOTAL AMB!,12F10.3,/)
C
C  BRANCH AROUND IF NOT AT PLUME CENTERLINE HEIGHT.
C
      IF(NZ.NE.3) GO TO 60
C
C  SAVE PLUME CENTERLINE CONCENTRATIONS, INCLUDING AMBIENT
C  BACKGROUND CONTRIBUTION.
C
      XNO2C=XNO2
      XSO4C=XSO4T
      XPRMC=XPT
 60   CONTINUE
      WRITE(6,5622)
 5622 FORMAT(////62H CUMULATIVE SURFACE DEPOSITION (MOLE FRACTION OF INI
     1TIAL FLUX),/)
      WRITE(6,5617) FDSO2
 5617 FORMAT(1H ,16X,4HSO2!,F10.4)
      WRITE(6,5618) FDNOX
 5618 FORMAT(1H ,16X,4HNOX!,F10.4)
      WRITE(6,5619) FDPART
 5619 FORMAT(21H PRIMARY PARTICULATE!,F10.4)
      WRITE(6,5620) FDSO4
 5620 FORMAT(1H ,16X,4HSO4!,F10.4)
      WRITE(6,5621) FDNO3
 5621 FORMAT(1H ,16X,4HNO3!,F10.4)
C
C CALCULATION OF NO2 AND SO4 FLUXES TAKING INTO ACCOUNT THE NON-
C UNIFORM MOLE RATIOS ACROSS THE PLUME.
C
      QNO2I(3) = 0.39*QNO2I(3) + 0.485*QNO2I(2) + 0.125*QNO2I(1)
      QNO2I(2) = 0.39*QNO2I(2) + 0.61*QNO2I(1)
      QNO2I(4)  = 0.39*QNO2I(4) + 0.61*QNO2I(5)
      QSO4=0.39*QSO4TR(3,NX)+0.485*QSO4TR(2,NX)+0.125*QSO4TR(1,NX)
C
C  SKIP OVER HORIZONTAL SIGHT PATHS WITH SKY BACKGROUND OPTICS
C  CALCULATION IF IFLG1 = 0 .
C
       IF(IFLG1.EQ.0) GO TO 7001
```

```
C ************************************************************************

C
C ************************************************************************
C
C VISUAL EFFECTS (HORIZONTAL SIGHT PATHS) *******************************
C
C ************************************************************************
C
C  LOOP FOR PLUME-BASED OR OBSERVER-BASED CALCULATIONS OR BOTH
C
      DO 7000 NC=NC1,NC2
      NFLAG=1
C
C  ALTITUDE LOOP, NZF=1 FOR PLUME CENTERLINE ONLY, NZF=2 FOR
C  CENTERLINE AND SURFACE.
C
      DO 7000 NZ1 = 1,NZF
      NZ=NZ1*3
      IF(NZ.EQ.3) Z=H
      IF(NZ.EQ.6) Z=0.
C
C  BRANCH FOR OBSERVER-SPECIFIC CALCULATION
C
      IF(NC.EQ.2)GO TO 6100
C
C  INITIALIZE AND INCREMENT SCATTERING ANGLE INDEX
C
      NT=NT1-1
 6990 NT=NT+1
      ITHETA=NT+1
C
C  ASSIGN SCATTERING ANGLE
C
      THETA=TT(ITHETA)
      NFLAG=-1*NFLAG
C
C  SKIP WRITING TITLE EVERY SECOND TIME THROUGH
C
      IF(NFLAG.GT.0) GO TO 65
 6100 CONTINUE
      WRITE(6,10)
      WRITE(6,61)(PLANT(J),J=1,6)
   61 FORMAT (20X,41HVISUAL EFFECTS FOR HORIZONTAL SIGHT PATHS,/20X,6A4,
     1/)
C
C  XKM = DOWNWIND DISTANCE IN KILOMETERS
C
      WRITE(6,52) XKM
C
C  H = HEIGHT OF PLUME CENTERLINE.
C
      WRITE(6,53) H
C
C  BRANCH IF DOING PLUME-BASED CALCULATION
C
      IF(NC.EQ.1)GO TO 6400
      WRITE(6,611)OBSPLU(NX)
  611 FORMAT(31H PLUME-OBSERVER DISTANCE (KM) =,F7.1)
      WRITE(6,612)AZMUTH(NX)
```

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C ************************************************************************

      612 FORMAT(27H AZIMUTH OF LINE-OF-SIGHT =,F7.1)
          WRITE(6,613)ABETA(NX)
      613 FORMAT(35H ELEVATION ANGLE OF LINE-OF-SIGHT =,F7.1)
          WRITE(6,614)ZENITH,TIME,IMO,IDAY
      614 FORMAT(21H SOLAR ZENITH ANGLE =,F7.1,2X,4H AT ,F5.0,4H ON ,
         1  I2,1H/,I2)
C
C  ASSIGN SCATTERING ANGLE
C
          THETA=TT(NX+7)
C
C   ASSIGN INDEX FOR PHASE FUNCTIONS FOR CALL TO PLMCLN
C
          ITHETA=7+NX
C
C  ASSIGN HORIZONTAL ANGLE BETWEEN OBSERVER LINE-OF-SIGHT AND PLUME
C  CENTERLINE.
C
          ALPHA=AALPHA(NX)
C
C  ASSIGN OBSERVER-PLUME DISTANCE ALONG LINE-OF-SIGHT
C
          RP=OBSPLU(NX)
C
C  ADJUST OPTICAL THICKNESS FOR LINE-OF-SIGHT NOT PERPENDICULAR TO PLUME
C
          YINT=CHIQIY(NZ)/SIN(ALPHA*RAD)
     6400 CONTINUE
          IF(NZ1.EQ.1) WRITE(6,62)
          IF(NZ1.EQ.2) WRITE(6,63)
      62  FORMAT(35H SIGHT PATH IS THROUGH PLUME CENTER,/)
      63  FORMAT(30H SIGHT PATH IS AT GROUND LEVEL,/)
          WRITE(6,64)
      64  FORMAT(6H THETA,1X,5HALPHA,2X,6HRP/RV0,4X,2HRV,2X,8H%REDUCED,4X,
         14HYCAP,7X,1HL,7X,1HX,7X,1HY,8H DELYCAP,4X,4HDELL,2X,6HC(550),2X,
         26HBRATIO,4X,4HDELX,4X,4HDELY,2X,6HE(LUV),2X,6HE(LAB))
      65  CONTINUE
          WRITE(6,66) THETA
C
C  BRANCH FOR OBSERVER-BASED CALCULATION
C
          IF(NC.EQ.2)GO TO 6500
      66  FORMAT(/,F6.0)
C
C  INITIALIZE AND INCREMENT INDEX FOR HORIZONTAL ANGLE BETWEEN
C OBSERVER LINE-OF-SIGHT AND PLUME CENTERLINE (PLUME-BASED CALCULATIONS)
C
          NA=0
     6995 NA=NA+1
          IF(NA.LT.5)GO TO 70
          ALPHA=AA(4)
          GO TO 73
  70      ALPHA=AA(NA)
C
C  CHI/Q AT PLUME CENTERLINE * EQUIVALENT DISTANCE TO MATCH CHI/Q
C  INTEGAL IN Y-DIRECTION FOR GAUSSIAN DISTRIBUTION.
C
  73      YINT=CHIQIY(NZ)/SIN(ALPHA*RAD)
```

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C ***********************************************************************

      NP=0
C
C  INITIALIZE AND INCREMENT OBSERVER-PLUME DISTANCE INDEX
C
 6999 NP=NP+1
C
C  RP = DISTANCE TO PLUME FROM OBSERVER ALONG LINE-OF-SIGHT
C
      RP=ROBJ(NP)*RVAMB
C
C   SPECIAL CASE FOR NA=5 FOR OBSERVER POSITIONED AT 1/2 OF A 22.5
C   DEGREE SECTOR FROM THE PLUME CENTERLINE.IF THIS DISTANCE IS <
C   5 KM, IT IS SET TO 5 KM.
C
      IF(NA.LT.5)GO TO 6500
      RP=AMAX1((DIST(NX)/1000.)*TAN(22.5/2.*RAD),5.)
 6500 CONTINUE
      PLMDIS=RP
C
C   CALCULATE RATIO OF PERPENDICULAR PLUME-OBSERVER DISTANCE TO SIGMA Y.
C
      RPR= RP/SY*1000.*SIN(ALPHA*RAD)
      YINTR=1.0
C
C  BRANCH IF OBSERVER TO PLUME DISTANCE IS GREATER THAN 2.17*SIGMA-Y
C
      IF(RPR.GT.2.17) GO TO 6601
C
C  REDEFINING RP IF OBSERVER IS WITHIN THE PLUME SO THAT RP IS DISTANCE
C  TO PLUME CENTROID.  ALSO, CALCULATE THE FRACTION OF TOTAL PLUME
C  OPTICAL THICKNESS WITHIN LINE OF SIGHT.
C
      RPHALF=0.18*(RPR+0.25)+0.153*(RPR+0.75)+0.167*(RPR+1.5)
      IF(RPR.GT.0.5)GO TO 6501
      YINTR1=(RPR/0.5)*0.18
      YINTR=YINTR1+0.50
      RP=((RPR*YINTR1/2.+RPHALF)/YINTR)*(SY/1000.)/SIN(ALPHA*RAD)
      GO TO 6601
6501  IF(RPR.GT.1.0)GO TO 6502
      YINTR1=(RPR-0.5)*0.153/0.5
      YINTR=YINTR1+0.68
      RP=(((RPR-0.5)*YINTR1/2.+(RPR-0.25)*0.18+RPHALF)/YINTR)*(SY/1000.)
     1 /SIN(ALPHA*RAD)
      GO TO 6601
6502  YINTR1=(RPR-1.0)*0.142
      YINTR=YINTR1+0.833
      RP=(((RPR-1.)*YINTR1/2.+(RPR-0.75)*0.153+(RPR-0.25)*0.18+RPHALF)
     1 /YINTR)*(SY/1000.)/SIN(ALPHA*RAD)
 6601 CONTINUE
      YINT1=YINT*YINTR
C
C  CALCULATION OF MASS INTEGRAL ALONG LINE-OF-SIGHT WITHIN PLUME FOR
C  PRIMARY PARTICULATE, SULFATE, AND NO2
C
      PLUMEP=YINT1*QPART
      PLUMES=YINT1*QSO4
      PLUMEN= YINT1*QNO2I(NZ)
      PLUMEO= YINT1*QPART*FRACTC
```

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C ***************************************************************************

C
C CALCULATION OF OPTICAL THICKNESS OF PLUME DUE TO SULFATE, NO2,
C AND PRIMARY PARTICULATE.
C
      TAPSO4 = BTASO4(19)*PLUMES
      TAPNO2 = ABSNO2(19)*PLUMEN
      TAUPRM = BTAPRM(19)*PLUMEP*(1.-FRACTC)+BTACAR(19)*PLUMEC
C
C CALCULATE BACKGROUND SKY INTENSITIES (SPECB) AND PLUME INTENSITIES
C (SPECP).   ********CALL PLMCLN*********
C
      CALL PLMCLN(ZENITH,0.,THETA,ITHETA,PLUMEP,PLUMES,PLUMEN,
     1PLUMEC,SPECB,SPECP,RP,THICK)
C     PRSU=(SPECP(4)+SPECP(5))/(SPECB(4)+SPECB(5))
C     PRSB=SPECP(9)/SPECB(9)
C     PRSG=SPECP(19)/SPECB(19)
C     PRSR=SPECP(27)/SPECB(27)
C     DO 966 I=1,39
C     XP(I)=SPECP(I)/10.
C     XB(I)=SPECB(I)/10.
C     XR(I)=XP(I)/XB(I)
C 966 CONTINUE
C     WRITE (6,94)(XP(I),I=1,39)
C     WRITE (6,94)(XB(I),I=1,39)
C     WRITE (6,94)(XR(I),I=1,39)
C  94 FORMAT(//5(7(1X,E13.4)/),4(1X,E13.4))
C
C  CALL ROUTINE TO CALCULATE COLORATION PARAMETERS
C
      CALL CHROMA(SPECP,SPECB)
 6608 CONTINUE
C
C NEXT CALCULATE REDUCTION IN VISUAL RANGE THROUGH PLUME DUE TO AEROSOL
C
      CORNO2=ALOG(CONT2+1.)
      THICK = TAPSO4 + TAUPRM + TAPNO2 + CORNO2
      SYALPH = (SY/1000.)/SIN(ALPHA*RAD)
C
C ADD IN OPTICAL DEPTH OF BACKGROUND AIR IN FRONT OF AND WITHIN
C PLUME.
C
      TAUPLU = BTABAC(19)*(PLMDIS + 2.17*SYALPH) + THICK
C
C BRANCH IF PLUME AEROSOL OPTICAL DEPTH = ZERO
C
      IF(THICK.EQ.0.) GO TO 6602
C
C BRANCH IF OPTICAL DEPTH OF AEROSOL IN FRONT OF PLUME AND OF PLUME
C AEROSOL IS NOT SUFFICIENT TO REDUCE VISUAL RANGE TO PREVENT SEEING
C BEYOND PLUME.
C
      IF(TAUPLU .LT. 3.912) GO TO 6602
      TAUHAF = BTABAC(19)*PLMDIS + ((YINTR-0.5)/YINTR)*THICK
      RESIDP = 3.912 - TAUHAF
      RESIDA = RESIDP
      IF(RESIDP .LT. 0.) RESIDA = -1.*RESIDP
      DELT1 = 0.18*THICK/YINTR + 0.5*SYALPH*BTABAC(19)
      DELT2 = 0.333*THICK/YINTR + SYALPH*BTABAC(19)
```

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C ***********************************************************************

      DELT3 = 0.5*THICK/YINTR + 2.17*SYALPH*BTABAC(19)
      RV = PLMDIS +((RESIDP/RESIDA)*(1. + 1.17*(RESIDA - DELT2)/
     1 (DELT3 - DELT2)))*SYALPH
      IF(RESIDA .LT. DELT2) RV = PLMDIS + (RESIDP/RESIDA)*(1. + (RESIDA-
     1 DELT1)/(DELT2 - DELT1))*0.5*SYALPH
      IF(RESIDA .LT. DELT1) RV = PLMDIS + 0.5*SYALPH*RESIDP/DELT1
      GO TO 6606
 6602 CONTINUE
C
C  CALCULATION OF DISTANCE OBSERVER WOULD SEE BEYOND PLUME
C
      BKPLM = (3.912 - TAUPLU)/BTABAC(19)
C
C  VISUAL RANGE = DISTANCE TO PLUME + WIDTH OF PLUME + DISTANCE
C  BEYOND PLUME.
C
      RV = PLMDIS + 2.17*SYALPH + BKPLM
 6606 CONTINUE
C
C  MINIMUM VISUAL RANGE LOOKING THROUGH PLUME CENTERLINE WITH
C  BACKGROUND EXTINCTION AND WITH PLUME SO4, NO2, AND PRIMARY
C  PARTICULATE EXTINCTION.
C
      RVMIN=3.912/(BTABAC(19) + BTASO4(19)*XSO4C + ABSNO2(19)*XNO2C
     1 + BTAPRM(19)*XPRMC*(1.-FRACTC) + XPRMC*FRACTC* BTACAR(19))
      IF(RV .LT. RVMIN) RV= RVMIN
      IF(RV.GT.RVAMB)RV=RVAMB
C
C  REDUCTION IN VISUAL RANGE LOOKING THROUGH THE PLUME
C
      REDRV=100.*(1.-RV/RVAMB)
      IF(NC.EQ.1)GO TO 6610
C
C  SAVE KEY VISUAL IMPACT PARAMETERS FOR PLOTTING LATER (OBSERVER-
C  BASED CASE)
C
      PLT1(NX,1)=REDRV
      PLT2(NX,1)=BRATIO
      PLT3(NX,1)=CONT2
      PLT4(NX,1)=DELAB
      GO TO 6607
C
C  SELECT THE PARTICULAR CASE FOR PLOTTING FOR THE PLUME-BASED
C  CALCULATION.
C  NP IS PLUME-OBSERVER DISTANCE INDEX, NA IS ALPHA INDEX,
C  NT IS SCATTERING ANGLE INDEX, AND NZ IS ALTITUDE INDEX.
C
 6610 IF(NP.NE.NPP)GO TO 6607
      IF(NA.NE.NAP)GO TO 6607
      IF(NT.NE.NTP)GO TO 6607
      IF(NZ.NE.NZP)GO TO 6607
C
C  SAVE THE KEY VISUAL IMPACT VALUES FOR THE DESIRED RP, THETA, ALPHA,
C  AND NZ FOR THE PLUME-BASED  PLOTS.
C
      PLOT1(NX,1)=REDRV
      PLOT2(NX,1)=BRATIO
      PLOT3(NX,1)=CONT2
```

```
C ************************************************************************

      PLOTM(NX,1)=DELAB
 6607 CONTINUE
      IF(NC.EQ.1) GO TO 6609
C
C  WRITE OUT RESULTS FOR OBSERVER-BASED CASE CALCULATIONS
C
      RPLMOB=OBSPLU(NX)/RVAMB
      WRITE(6,67) ALPHA,RPLMOB,RV.REDRV,YCAP,VAL,X,Y,YCAPD,VALD,CONT2,
     1BRATIO,XD,YD,DELUV,DELAB
      GO TO 7000
 6609 CONTINUE
      RROBJT=ROBJ(NP)
      IF(NA.EQ.5)RROBJT=RP/RVAMB
C
C  WRITE OUT RESULTS FOR PLUME-BASED CASE CALCULATIONS
C
      IF(NA.EQ.5)WRITE(6,88)
88    FORMAT(1H0,4X,127HOBSERVER POSITION AT 1/2 OF A 22.5 DEGREE WIND D
     1IRECTION SECTOR FROM THE PLUME CENTERLINE AT THE GIVEN DISTANCE FR
     2OM THE SOURCE,/)
      WRITE(6,67) ALPHA,RROBJT,RV,REDRV,YCAP,VAL,X,Y,YCAPD,VALD,
     1CONT2,BRATIO,XD,YD,DELUV,DELAB
67    FORMAT(5X,F8.0,F8.2,F8.1,3F8.2,2F8.4,2F8.2,6F8.4)
C
C  TEST IF DISTANCE, ALPHA, AND THETA LOOPS ARE COMPLETED.
C
      IF(NP.LT.6 .AND. NA .LT. 5)GO TO 6999
      IF(NA.LT.5)GO TO 6995
      IF(NT.LT.(NT2-1))GO TO 6990
 7000 CONTINUE
 7001 CONTINUE
      CHIQIZ=(TAMB/PGTEMP)/(SQRT(2.*PI)*SY*U)
      CHIQIZ=CHIQIZ/1000.
C
C  BRANCH AROUND NON-HORIZONTAL SIGHT PATHS CALCULATIONS IF IFLG2
C  WAS SET TO ZERO.
C
      IF(IFLG2.EQ.0) GO TO 8001
C
C ************************************************************************
C
C  **** NON-HORIZONTAL SIGHT PATHS CALCULATIONS *************************
C
C ************************************************************************
C
C LOOP ON TYPES OF CALCULATIONS (PLUME-BASED OR OBSERVER-BASED OR BOTH)
C
      DO 8000 NC=NC1,NC2
C
C  IF SPECIFIC CASE BETA LESS THAN 5 DEGREES, SKIP CALCULATION.
C
      IF(NC.EQ.2.AND.ABETA(NX).LT.5.)GO TO 8001
C
C  BRANCH FOR SPECIFIC CASE CALCULATION
C
 7110 IF(NC.EQ.2)GO TO 7100
      NFLAG=1
C
```

```
C ***********************************************************************

C  INITIALIZE AND INCREMENT SCATTERING ANGLE INDEX
C
      NT=NT1-1
 7996 NT=NT+1
      ITHETA=NT+1
C
C  ASSIGN SCATTERING ANGLE
C
      THETA=TT(ITHETA)
      NFLAG=-1*NFLAG
      IF(NFLAG.GT.0) GO TO 75
 7100 CONTINUE
      WRITE(6,10)
      WRITE(6,71)(PLANT(J),J=1,6)
   71 FORMAT(20X,70HVISUAL EFFECTS FOR NON-HORIZONTAL CLEAR SKY VIEWS TH
     1ROUGH PLUME CENTER,//,20X,6A4,//)
C
C  XRM = DOWNWIND DISTANCE IN KM
C  H = PLUME CENTERLINE HEIGHT
C  BRANCH IF DOING PLUME-BASED CALCULATION
C
      WRITE(6,52) XRM
      WRITE(6,53) H
      IF(NC.EQ.1)GO TO 7200
C
C  WRITE OUT DISTANCE FROM OBSERVER TO PLUME ALONG LINE-OF-SIGHT.
C
      WRITE(6,611)OBSPLU(NX)
C
C  WRITE OUT AZIMUTH OF OBSERVER LINE-OF-SIGHT TO PLUME
C
      WRITE(6,612)AZMUTH(NX)
C
C  WRITE OUT ELEVATION ANGLE OF OBSERVER LINE-OF-SIGHT.
C
      WRITE(6,613)ABETA(NX)
C
C  WRITE OUT SOLAR ZENITH ANGLE, TIME OF DAY, MONTH, DAY OF MONTH
C
      WRITE(6,614)ZENITH,TIME,IMO,IDAY
C
C  ASSIGN SCATTERING ANGLE AND INDEX FOR SCATTERING PHASE FUNCTIONS.
C
      THETA=TT(NX+7)
      ITHETA=7+NX
C
C  ASSIGN HORIZONTAL ANGLE BETWEEN PLUME CENTERLINE AND LINE-OF-SIGHT
C
      ALPHA=AALPHA(NX)
C
C  ASSIGN ELEVATION ANGLE FOR LINE OF SIGHT TO POINT ON PLUME CENTERLINE
C
      BETA=ABETA(NX)
C
C  ASSIGN DISTANCE TO PLUME CENTERLINE ALONG LINE-OF-SIGHT.
C
      RP=OBSPLU(NX)
 7200 CONTINUE
```

```
C ************************************************************************


        WRITE(6,72)
   72   FORMAT(/,6H THETA,3X,5HALPHA,4X,4HBETA,6X,2HRP,
       14X,4HYCAP,7X,1HL,7X,1HX,7X,1HY,8H DELYCAP,4X,4HDELL,2X,6HC(550),
       2 2X,6HBRATIO,4X,4HDELX,4X,4HDELY,2X,6HE(LUV),2X,6HE(LAB))
   75   CONTINUE
        WRITE(6,66) THETA
C
C  BRANCH FOR OBSERVER-BASED CASE CALCULATIONS.
C
        IF(NC.EQ.2)GO TO 7300
C
C  INITIALIZE AND INCREMENT FOR LOOP ON ALPHA ANGLE
C
        NA=0
  7997 NA=NA+1
        ALPHA=AA(NA)
C
C  INITIALIZE AND INCREMENT FOR LOOP ON OBSERVER LINE-OF-SIGHT
C  ELEVATION ANGLE.
C
          NB=0
  7999 NB=NB+1
        BETA=15.*FLOAT(NB)
C
C  CALCULATION OF OBSERVER LINE-OF-SIGHT TO PLUME DISTANCE.
C
        DELZ=H*1.E-3
        DELXY=DELZ*COS(BETA*RAD)/SIN(BETA*RAD)
        DELX=DELXY*COS(ALPHA*RAD)
        DELY=DELXY*SIN(ALPHA*RAD)
        RP=SQRT(DELZ*DELZ+DELY*DELY+DELX*DELX)
  7300 CONTINUE
        CY=CHIQIY(3)*COS(BETA*RAD)
        CZ=CHIQIY(3)*SIN(BETA*RAD)
        YZINT=SQRT(CY*CY+CZ*CZ)/SIN(ALPHA*RAD)
        PLUMEP=YZINT*QPART
        PLUMEC=YZINT*QPART*FRACTC
        PLUMES=YZINT*(QSO4+QNO3)
        PLUMEN=YZINT*QNO2I(3)
C
C  CALL ROUTINE TO CALCULATE SKY INTENSITIES FOR PLUME AND SKY
C  WITHOUT PLUME.
C
        CALL PLMCLN(ZENITH,BETA,THETA,ITHETA,PLUMEP,PLUMES,PLUMEN,
      1 PLUMEC,SPECB,SPECP,RP,THICK)
C
C  CALL ROUTINE TO CALCULATE COLORATION PARAMETERS.
C
        CALL CHROMA(SPECP,SPECB)
        WRITE(6,78) ALPHA,BETA,RP,YCAP,VAL,X,Y,YCAPD,VALD,CONT2,
      1BRATIO,XD,YD,DELUV,DELAB
   78   FORMAT(5X,2F8.0,3F8.2,2F8.4,2F8.2,6F8.4)
C
C  CHECK IF END OF LOOPS FOR PLUME-BASED CALCULATION.
C
        IF(NC.EQ.2)GO TO 8000
        IF(NB.LT.6)GO TO 7999
        IF(NA.LT.4)GO TO 7997
```

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C ***********************************************************************

          IF(NT.LT.(NT2-1))GO TO 7996
 9000 CONTINUE
 8001 CONTINUE
          IF(IFLG3.EQ.0) GO TO 9001
C
C ***********************************************************************
C
C  ***** WHITE, GRAY, AND BLACK OBJECT VIEWS ****************************
C
C ***********************************************************************
C
C  OPTICAL EFFECTS ON VIEW OF OBJECT BEHIND PLUME.
C  CALCULATION OF PLUME PARTICULATE, SULFATE, AND NO2 INTEGRAL
C  ACROSS PLUME.
C
          PLUMEP=CHIQIY(3)*QPART
          PLUMES=CHIQIY(3)*(QSO4+QNO3)
          PLUMEN=CHIQIY(3)*QNO2I(3)
          PLUMEC=CHIQIY(3)*QPART*FRACTC
C
C  LOOP FOR PLUME-BASED, OBSERVER-BASED, OR BOTH TYPES OF CALCULATIONS
C
          DO 9000 NC=NC1,NC2
C
C  BRANCH IF DOING THE PLUME-BASED CALCULATION
C
          IF(NC.EQ.1) GO TO 8002
C
C  ADJUST FOR OBSERVER-BASED ALPHA FOR SPECIFIC POINT
C
          [illegible]=SIN(AALPHA(NX)*RAD)
          PLUMEP=PLUMEP/F3
          PLUMES=PLUMES/F3
          PLUMEN=PLUMEN/F3
          PLUMEC=PLUMEC/F3
 8002 CONTINUE
C
C  BRANCH IF DOING THE OBSERVER-BASED CALCULATION.
C
          IF(NC.EQ.2)GO TO 8100
C
C  INITIALIZE AND INCREMENT SCATTERING ANGLE INDEX FOR PLUME-BASED
C  CASE CALCULATION.
C
          NT=NT1-1
 8995 NT=NT+1
          ITHETA=NT+1
          THETA=TT(ITHETA)
 8100 CONTINUE
          WRITE(6,10)
          IF(NC.EQ.1)WRITE(6,81)(PLANT(J),J=1,6)
          IF(NC.EQ.2)WRITE(6,87)(PLANT(J),J=1,6)
 81   FORMAT(10X,41HPLUME VISUAL EFFECTS FOR HORIZONTAL VIEWS,/,10X,
     160HPERPENDICULAR TO THE PLUME OF WHITE, GRAY, AND BLACK OBJECTS,/,
     210X,56HFOR VARIOUS OBSERVER-PLUME AND OBSERVER-OBJECT DISTANCES,
     3//10X,6A4,//)
 87   FORMAT(10X,41HPLUME VISUAL EFFECTS FOR HORIZONTAL VIEWS,/,10X,
     146HOF THE PLUME OF WHITE, GRAY, AND BLACK OBJECTS,/,
C ***********************************************************************

     210X,57HFOR SPECIFIC OBSERVER-PLUME AND OBSERVER-OBJECT DISTANCES,
     3//10X,6A4,//)
      WRITE(6,52) XKM
C
C  BRANCH IF DOING PLUME-BASED CALCULATION
C
      IF(NC.EQ.1)GO TO 84
      WRITE(6,611)OBSPLU(NX)
      WRITE(6,612)AZMUTH(NX)
      WRITE(6,613)ABETA(NX)
      WRITE(6,614)ZENITH,TIME,IMO,IDAY
C
C  ASSIGN SPECIFIC SCATTERING ANGLE AND INDEX FOR SCATTERING ANGLE PHASE
C   FUNCTIONS.
C
      THETA=TT(NX+7)
      ITHETA=7+NX
   84 WRITE(6,82)THETA
   82 FORMAT(9H THETA = ,F5.0)
      WRITE(6,83)
   83 FORMAT(/,1X,7HREFLECT,2X,6HRP/RV0,2X,6HRO/RV0,4X,4HYCAP,7X,1HL,7X,
     11HX,7X,1HY,8H DELYCAP,4X,4HDELL,2X,6HC(550),2X,6HBRATIO,4X,4HDELX,
     24X,4HDELY,2X,6HE(LUV),2X,6HE(LAB),/)
C
C  LOOP ON REFLECTIVITY OF OBJECT (K=1 FOR WHITE, K=2 FOR GRAY, K=3 FOR
C  BLACK)
C
      DO 8999 K=1,3
      XLUMIN=REFL(K)/(2.*PI)
C
C  BRANCH IF OBSERVER-BASED CASE
C
      IF(NC.EQ.2)GO TO 86
C
C  INITIALIZE AND INCREMENT INDEX FOR OBSERVER TO PLUME DISTANCE
C  ALONG LINE-OF-SIGHT.
C
      IP=0
 8996 IP=IP+1
      NRO=7-IP
C
C  INITIALIZE AND INCREMENT INDEX FOR DISTANCE FROM OBSERVER TO
C  BACKGROUND OBJECT ALONG LINE-OF-SIGHT.
C
      IO1=0
 8997 IO1=IO1+1
      RP=ROBJ(IP)*RVAMB
      IPIO1=IP+IO1-1
      RO=ROBJ(IPIO1)*RVAMB
      RPR=(RP/SY)*1000.
      ROR=((RO-RP)/SY)*1000.
      IF(RPR.GT.2.17.AND.ROR.GT.2.17)GO TO 8991
C
C   IF OBSERVER OR OBJECT BACKGROUND IS WITHIN THE PLUME, CHANGE THE
C   OBSERVER-TO-PLUME DISTANCE TO BE THE DISTANCE TO THE CENTROID OF
C   THE AREA UNDER THE GAUSSIAN CURVE FOR THE PLUME BETWEEN THE
C   OBSERVER AND THE BACKGROUND OBJECT.
C
```

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C ************************************************************************

      CALL PLMIN(RPR,ROR,SY,RP,YINTR)
      PLUMP1=PLUMEP*YINTR
      PLUMS1=PLUMES*YINTR
      PLUMN1=PLUMEN*YINTR
      PLUMC1=PLUMEC*YINTR
C
C  CALL ROUTINE TO CALCULATE INTENSITIES FOR OBJECT W/O PLUME
C  (SPECO) AND WITH PLUME (SPECP).
C
      CALL PLMOBJ(ZENITH,BETA,THETA,ITHETA,PLUMP1,PLUMS1,PLUMN1,
     1PLUMC1,XLUMIN,RO,RP,SPECO,SPECP)
      GO TO 89
8991  CALL PLMOBJ(ZENITH,BETA,THETA,ITHETA,PLUMEP,PLUMES,PLUMEN,
     1PLUMEC,XLUMIN,RO,RP,SPECO,SPECP)
C
C  CALL ROUTINE TO CALCULATE COLORATION PARAMETERS.
C
89    CALL CHROMA(SPECP,SPECO)
      IPIO1=IP+IO1-1
      WRITE(6,85) REFL(K),ROBJ(IP),ROBJ(IPIO1),YCAP,VAL,X,Y,YCAPD,
     1VALD,CONT2,BRATIO,XD,YD,DELUV,DELAB
 85   FORMAT(F8.1,4F8.2,2F8.4,2F8.2,6F8.4)
C
C  SPECIFY OBJECT DISTANCE, PLUME-OBSERVER DISTANCE, AND SCATTERING ANGLE
C  FOR SAVING RESULTS TO BE PLOTTED.
C
      IF(IO1.NE.IO1P)GO TO 8990
      IF(IP.NE.IPP)GO TO 8990
      IF(NT.NE.NTP)GO TO 8990
C
C  VISUAL RANGE REDUCTION IS DEFINED FOR CLEAR SKY ONLY.
C
      PLOT1(NX,K+1)=0.
      PLOT2(NX,K+1)=BRATIO
      PLOT3(NX,K+1)=CONT2
      PLOT4(NX,K+1)=DELAB
C
C  CHECK IF END OF LOOP ON BACKGROUND OBJECT DISTANCE INDEX.
C
8990  IF(IO1.LT.NRO)GO TO 8997
C
C  CHECK IF END OF LOOP ON OBSERVER-PLUME DISTANCE INDEX.
C
      IF(IP.LT.6)GO TO 8996
       GO TO 8999
C
C  CONTINUE WITH OBSERVER-BASED CALCULATION.  ASSIGN SCATTERING ANGLE.
C
   86 ITHETA=7+NX
      THETA=TT(ITHETA)
      RP=OBSPLU(NX)
C
C  JUMP OUT OF CALCULATION IF OBJECT IS BETWEEN CENTER
C  OF PLUME AND OBSERVER.
C
      IF(OBSPLU(NX).GT.ROBJT(NX))WRITE(6,90)
90    FORMAT(10X,85HBACKGROUND OBJECT IS BETWEEN OBSERVER AND CENTER OF
     1PLUME AND CALCULATION IS STOPPED.)
```

```
C *******************************************************************

      IF(OBSPLU(NX).GT.ROBJT(NX))GO TO 9000
      RPR=(RP/SY)*1000.
      ROR=((ROBJT(NX)-RP)/SY)*1000.
      IF(RPR.GT.2.17.AND.ROR.GT.2.17)GO TO 8992
C
C   IF OBSERVER OR OBJECT IS WITHIN THE PLUME, CHANGE THE OBSERVER-TO-
C   PLUME DISTANCE TO BE THE DISTANCE TO THE CENTROID OF THE AREA UNDER
C   THE GAUSSIAN CURVE FOR THE PLUME BETWEEN THE OBSERVER AND THE BACK-
C   GROUND OBJECT.
C
      CALL PLMIN(RPR,ROR,SY,RP,YINTR)
C
C   CORRECT FOR VIEWS NOT PERPENDICULAR TO THE PLUME CENTERLINE
C
      RP=RP/SIN(AALPHA(NX)*RAD)
      PLUMP1=PLUMEP*YINTR
      PLUMS1=PLUMES*YINTR
      PLUMN1=PLUMEN*YINTR
      PLUMC1=PLUMEC*YINTR
C
C  CALL ROUTINE TO CALCULATE INTENSITIES WITH AND WITHOUT PLUME.
C
      CALL PLMOBJ(ZENITH,ABETA(NX),THETA,ITHETA,PLUMP1,PLUMS1,
     1 PLUMN1,PLUMC1,XLUMIN,ROBJT(NX),RP,SPECO,SPECP)
      GO TO 91
8992  CALL PLMOBJ(ZENITH,ABETA(NX) ,THETA,ITHETA,PLUMEP,PLUMES,
     1 PLUMEN,PLUMEC,XLUMIN,ROBJT(NX),RP,SPECO,SPECP)
C
C  CALL ROUTINE TO CALCULATE COLORATION PARAMETERS.
C
91    CALL CHROMA(SPECP,SPECO)
C
C  SAVE RESULTS FOR PLOTTING.
C
      PLT1(NX,K+1)=0.
      PLT2(NX,K+1)=BRATIO
       PLT3(NX,K+1)=CONT2
      PLT4(NX,K+1)=DELAB
 8998 CONTINUE
      RPLMOB=OBSPLU(NX)/RVAMB
      RROBJT=ROBJT(NX)/RVAMB
      WRITE(6,85)REFL(K),RPLMOB,RROBJT,YCAP,VAL,X,Y,YCAPD,VALD,
     1 CONT2,BRATIO,XD,YD,DELUV,DELAB
 8999 CONTINUE
C
C  CHECK IF LOOP ON SCATTERING ANGLE FOR PLUME-BASED CASE IS COMPLETED
C
      IF(NC.EQ.1.AND.NT.LT.(NT2-1))GO TO 8995
 9000 CONTINUE
 9001 CONTINUE
C
C  SKIP VISUAL EFFECTS ALONG PLUME IF IFLG4=0
C
      IF(IFLG4.EQ.0)GO TO 1301
C
C *******************************************************************
C
C** VISUAL EFFECTS ALONG PLUME ******************************************
```

```
C ************************************************************************
```

```
C
C ************************************************************************
C
C LOOP ON TYPE OF CALCULATION: PLUME-BASED, OBSERVER-BASED, OR BOTH.
C
      DO 1300 NC=NC1,NC2
C
C  LOOP FOR CALC AT PLUME CL AND AT GROUND.
C
      DO 1300 NZ1=1,NZF
      NZ=NZ1*3
      IF(NZ.EQ.3)Z=H
      IF(NZ.EQ.6)Z=0.
C
C  BRANCH IF DOING OBSERVER-BASED CALCULATION.
C
      IF(NC.EQ.2)GO TO 1002
C
C  INITIALIZE AND INCREMENT LOOP FOR SCATTERING ANGLE
C
      NT=NT1-1
1001  NT=NT+1
      ITHETA=NT+1
      THETA=TT(ITHETA)
1002  CONTINUE
      WRITE(6,10)
      WRITE(6,1010)(PLANT(J),J=1,6)
1010  FORMAT(10X,45HVISUAL EFFECTS FOR LINES OF SIGHT ALONG PLUME//,10X,
     1 6A4//)
      WRITE(6,52)XKM
C
C  BRANCH FOR PLUME-BASED CALCULATION.
C
      IF(NC.EQ.1)GO TO 1005
      WRITE(6,611)OBSPLU(NX)
      WRITE(6,612)AZMUTH(NX)
      WRITE(6,613)ABETA(NX)
      WRITE(6,614)ZENITH,TIME,IMO,IDAY
C
C  ASSIGN PLUME-BASED CASE SCATTERING ANGLE AND SCATTERING PHASE FUNCTION
C  INDEX.
C
      THETA=TT(NX+7)
      ITHETA=7+NX
1005  CONTINUE
      WRITE(6,1020)
1020  FORMAT(6H THETA,1X,6HLENGTH,1X,6HRP/RV0,4X,2HRV,2X,8H%REDUCED,4X,
     1 4HYCAP,7X,1HL,7X,1HX,7X,1HY,8H DELYCAP,4X,4HDELL,2X,6HC(550),2X,
     2 6HBRATIO,4X,4HDELX,4X,4HDELY,2X,6HE(LUV),2X,6HE(LAB))
1021  CONTINUE
      WRITE(6,66)THETA
C
C  BRANCH IF DOING PLUME-BASED CASE CALCULATION
C
      IF(NC.EQ.1)GO TO 1008
C
C  OBLIQUE ANGLE CALCULATIONS FOR SPECIFIC CASE
C  CONCENTRATIONS FOR PRIMARY PARTICULATE, SO4, AND NO2
```

```
C ************************************************************************
C
      CPAVE=XPARTP(NX,NZ)
      CSAVE=XPARTS(NX,NZ)
      CNAVE=XNO2I(NX,NZ)
      CARAVE=XPARTP(NX,NZ)*FRACTC
C
C DISTANCE WITHIN PLUME
C
       XALONG =((SY/1000.)*SQRT(PI*2.))/(SIN(AALPHA(NX)*RAD))
      XLONG2=XALONG/2.
C
C CHECK IF OBSERVER IN PLUME, IF YES , MODIFY XALONG
C
      IF(OBSPLU(NX).LT.XLONG2)XALONG=OBSPLU(NX)+XLONG2
C
C CALCULATIONS FOR CLEAR SKY AND THREE BACKGROUND REFLECTANCES.
C
      ALONG=OBSPLU(NX)-XLONG2
      IF(ALONG.LT.0.0)ALONG=0.0
      DO 1009 K=1,4
C
C K=1 FOR CLEAR SKY, K=2 FOR WHITE OBJECTS, K=3 FOR GRAY OBJECTS,
C K=4 FOR BLACK OBJECTS.
C BRANCH IF K > 1
C
      IF(K.GT.1)GO TO 1025
C
C BACKGROUND CLEAR SKY CASE
C CALL ROUTINE TO DEFINE BACKGROUND SKY INTENSITY WITHOUT PLUME
C
      CALL BACCLN(ZENITH,0.,THETA,ITHETA,SPECB)
      GO TO 1026
 1025 CONTINUE
C
C CALCULATION FOR BACKGROUND OBJECT.
C
C DISTANCE CALULATIONS ARE THE SAME FOR K = 2, 3, 4.
C
      IF(ROBJT(NX).LE.0.0)GO TO 1009
      XLUMIN=REFL(K-1)/(2.*PI)
C
C DISTANCE CALCULATIONS DONE ONCE FOR K=2 / SKIP AROUND FOR K =3,4
C
      IF(K.GT.2)GO TO 95
C
C DISTANCE FROM OBJECT TO BACK SIDE OF PLUME
C
      RO=ROBJT(NX)-(OBSPLU(NX)+XLONG2)
C
C RESET RO IF OBJECT IS WITHIN BACK SIDE OF PLUME
C
      IF((ROBJT(NX)-OBSPLU(NX)).LT.XLONG2)RO=0.
C
C XALONG IS THE DISTANCE THAT THE LINE OF SIGHT IS WITHIN PLUME.
C  RECALCULATE  XALONG IF OBJECT IS WITHIN BACK SIDE OF PLUME AND
C  OBSERVER IS OUTSIDE PLUME.
C
      IF((ROBJT(NX)-OBSPLU(NX)).LT.XLONG2)XALONG=XLONG2+(ROBJT(NX)-
C ************************************************************************
     1 OBSPLU(NX))
C
C ADJUSTMENT IF BOTH OBJECT AND OBSERVER ARE IN FRONT OF PLUME.
C
      IF(OBSPLU(NX).LT.XLONG2)GO TO 97
      IF(ROBJT(NX).LT.(OBSPLU(NX)-XLONG2))GO TO 96
      GO TO 97
 96   XALONG=0.
      RO=0.
      ALONG=ROBJT(NX)
 97   CONTINUE
C
C ADJUSTMENT IF BOTH OBSERVER AND BACKGROUND OBJECT ARE WITHIN FRONT
C SIDE OF PLUME
C
      IF(ROBJT(NX).GT.OBSPLU(NX))GO TO 98
      IF(OBSPLU(NX).GT.XLONG2)GO TO 98
      XALONG=ROBJT(NX)
      ALONG=0.
      RO=0.
 98   CONTINUE
C
C  ADJUSTMENT IF OBSERVER IS OUTSIDE PLUME AND BACKGROUND OBJECT IS
C  WITHIN FRONT SIDE OF PLUME.
C
      IF(ROBJT(NX).GT.OBSPLU(NX))GO TO 104
      IF(ROBJT(NX).LT.(OBSPLU(NX)-XLONG2))GO TO 104
      IF((OBSPLU(NX)-XLONG2).LE.0.)GO TO 104
      RO=0.
      XALONG=ROBJT(NX)-(OBSPLU(NX)-XLONG2)
      ALONG=OBSPLU(NX)-XLONG2
 104  CONTINUE
C
C ADJUSTMENT FOR OBSERVER WITHIN FRONT SIDE OF PLUME AND OBJECT
C BEHIND PLUME.
C
      IF(OBSPLU(NX).GT.XLONG2)GO TO 102
      IF(ROBJT(NX).LT.(OBSPLU(NX)+XLONG2))GO TO 102
      XALONG=XLONG2+OBSPLU(NX)
      RO=ROBJT(NX)-(OBSPLU(NX)+XLONG2)
      ALONG=0.
 102  CONTINUE
C
C ADJUSTMENT FOR OBSERVER WITHIN FRONT SIDE OF PLUME AND OBJECT
C WITHIN BACK SIDE OF PLUME.
C
      IF(OBSPLU(NX).GT.XLONG2)GO TO 103
      IF(ROBJT(NX).LT.OBSPLU(NX))GO TO 103
      IF(ROBJT(NX).GT.(OBSPLU(NX)+XLONG2))GO TO 103
      RO=0.
      ALONG=0.
      XALONG=ROBJT(NX)
 103  CONTINUE
 95   CONTINUE
C
C CALL ROUTINE TO CALCULATE INTENSITY FOR BACKGROUND OBJECT
C AT BACK SIDE OF PLUME.
C
```

```
C ***********************************************************************
      CALL BACOBJ(ZENITH,0.,THETA,ITHETA,RO,SPECB,XLUMIN)
 1026 CONTINUE
C
C  STORE BACKGROUND INTENSITIES AT BACK SIDE OF PLUME IN SPECP ARRAY.
C
      DO 1027 I=1,39
      SPECP(I)=SPECB(I)
 1027 CONTINUE
C
C     INTENSITY FOR PLUME SEGMENT(LINE OF SIGHT FOR SPECIFIC CASE, NOT
C     NECESSARILY ON PLUME CENTERLINE.
C
      CALL PLMAX(ZENITH,BETA,THETA,ITHETA,CPAVE,CSAVE,CNAVE,CARAVE,
     1 XALONG,SPECP,SPECB)
C
C  INTENSITY CHANGE FOR BACKGROUND AIR BETWEEN PLUME AND OBSERVER
C
      CALL PLMAX(ZENITH,BETA,THETA,ITHETA,0.,0.,0.,0.,ALONG,SPECP,SPECB)
C
C  CALL ROUTINE TO CALCULATE COLORATION PARAMETERS
C
      CALL CHROMA(SPECP,SPECB)
C
C  OPTICAL DEPTH BETWEEN OBSERVER AND PLUME
C
      TAUTOT=BTABAC(19)*ALONG
      TAU1=TAUTOT
C
C  OPTICAL DEPTH DUE TO PLUME PRIMARY PARTICULATE AND SO4
C
      TAUTOT=TAUTOT+XALONG*(CPAVE*BTAPRM(19)+CSAVE*BTASO4(19)+
     1 BTABAC(19)+CNAVE*ABSNO2(19)+CARAVE*BTACAR(19))+ALOG(CONT2+1.)
C
C  CHECK IF OPTICAL DEPTH .GT. VISUAL RANGE LIMIT
C
      IF(TAUTOT.GT.3.912)GO TO 1006
C
C  REDUCTION IN VISUAL RANGE
C
      DELRV=(3.912-TAUTOT)/BTABAC(19)
      RV=XALONG+ALONG+DELRV
      GO TO 1007
 1006 DELRV=(3.912-TAU)/(TAUTOT-TAU1)
      RV=ALONG+DELRV
 1007 REDRV=((RVAMB-RV)/RVAMB)*100.
      RR=OBSPLU(NX)/RVAMB
      IF(K.EQ.1)WRITE(6,47)
 47   FORMAT(5X,19HFOR SKY BACKGROUND:)
      IF(K.EQ.2)WRITE(6,74)
 74   FORMAT(5X,21HFOR WHITE BACKGROUND:)
      IF(K.EQ.3)WRITE(6,76)
 76   FORMAT(5X,20HFOR GRAY BACKGROUND:)
      IF(K.EQ.4)WRITE(6,77)
 77   FORMAT(5X,21HFOR BLACK BACKGROUND:)
      WRITE(6,67)XALONG,RR,RV,REDRV,YCAP,VAL,X,Y,YCAPD,VALD,CONT2,
     1 BRATIO,XD,YD,DELUV,DELAB
 1009 CONTINUE
C
```

```
C ************************************************************************

C END OF CALCULATIONS FOR NO=2
C
      GO TO 1300
 1008 CONTINUE
C
C  PLUME-BASED CALCULATIONS FOR PLUME CENTERLINE.
      NXEND=NX-1
C  IF NX=1, SKIP OVER CALCULATION
C
      IF(NXEND.EQ.0)GO TO 1300
C
C  LOOP ON NUMBER OF PLUME SEGMENTS
C  LOOP ON PLUME SIGMENTS THAT CAN BE IN OBSERVER'S LINE-OF-SIGHT
C
      DO 1200 NXIN=1,NXEND
      NXX1=NX-NXIN
C
C  CALL ROUTINE TO CALCULATE INTENSITIES FOR BACKGROUND SKY
C  WITHOUT PLUME.
C
      CALL BACCLN(ZENITH,0.,THETA,ITHETA,SPECB)
      DO 1022 I=1,39
 1022 SPECP(I)=SPECB(I)
C
C  LOOP ON PLUME SEGMENTS BETWEEN DISTANCE NX AND FIRST POINT.
C
      DO 1100 NXX=NXX1,NXEND
C
C  USE MEANS OF END POINTS OF SEGMENTS TO DEFINE CONCENTRATIONS
C
      CPAVE=(XPARTP(NXX,NZ)+XPARTP(NXX+1,NZ))/2.
      CSAVE=(XPARTS(NXX,NZ)+XPARTS(NXX+1,NZ))/2.
      CNAVE=(XNO2I(NXX,NZ)+XNO2I(NXX+1,NZ))/2.
      CARAVE=CPAVE*FRACTC
C
C  DISTANCE WITHIN PLUME IN KILOMETERS.
C
      XALONG=(DIST(NXX+1)-DIST(NXX))/1000.
C
C  CHANGE INTENSITY FOR EACH SEGMENT OF PLUME (1 POINT TO THE NEXT).
C
      CALL PLMAX(ZENITH,BETA,THETA,ITHETA,CPAVE,CSAVE,CNAVE,CARAVE,
     1 XALONG,SPECP,SPECB)
 1100 CONTINUE
C
C  NESTED LOOP FOR VARIOUS OBSERVER-TO-PLUME-SEGMENT DISTANCES.
C
      DO 1200 NROBJ=1,7
      NR1=NROBJ-1
      XALONG=0.
C
C  ROBJ NOT DEFINED FOR INDEX .LT. 1, THEREFORE NO INPUT BY AIRLIGHT
C  BETWEEN PLUME AND OBSERVER.
C
      IF(NROBJ.EQ.1)GO TO 1115
      IF(NROBJ.EQ.2)GO TO 1111
      GO TO 1112
C
```

```
C ***************************************************************************

C  DISTANCE OF LINE-OF-SIGHT FROM OBSERVER TO PLUME SEGMENT.
C
1111  XALONG=ROBJ(NR1)*RVAMB
      GO TO 1110
1112  CONTINUE
      XALONG=(ROBJ(NR1)-ROBJ(NR1-1))*RVAMB
1110  CALL PLMAX(ZENITH,BETA,THETA,ITHETA,0.,0.,0.,0.,XALONG,SPECP
     1,SPECB)
1115  CONTINUE
C
C  CALCULATE COLORATION PARAMETERS
C
      CALL CHROMA(SPECP,SPECB)
      IF(NROBJ.EQ.1)GO TO 1116
      GO TO 1117
1116  TAUTOT=0.
      GO TO 1118
1117  CONTINUE
C
C  OPTICAL DEPTH DUE TO AMBIENT BACKGROUND AIR
C
      TAUTOT=BTABAC(19)*RVAMB*ROBJ(NR1)
1118  NXX=0
C
C  NESTED LOOP ON DISTANCE WITHIN PLUME TO DETERMINE VISUAL RANGE.
C
1120  NXX=NXX+1
      TAUT1=TAUTOT
C
C  DISTANCE WITHIN PLUME SEGMENT
C
      NXDIFF=NX-NXX
      XALONG=(DIST(NXDIFF+1)-DIST(NXDIFF))/1000.
C
C  ADD OPTICAL DEPTH FOR PRIMARY PARTICULATE
C
      TAUTOT=TAUTOT+XALONG*BTAPRM(19)*(XPARTP(NXDIFF+1,NZ)+XPARTP(NXDI
     1FF,NZ))*(1.-FRACTC)/2. + BTACAR(19)*FRACTC*(XPARTP(NXDIFF+1,NZ)
     2 + XPARTP(NXDIFF,NZ))*XALONG/2.
C
C  ADD OPTICAL DEPTH FOR SO4
C
      TAUTOT=TAUTOT+XALONG*BTASO4(19)*(XPARTS(NXDIFF+1,NZ)+XPARTS(NXDI
     1FF,NZ))/2.
C
C  ADD OPTICAL DEPTH FOR NO2 ABSORPTION.
C
      TAUTOT=TAUTOT+XALONG*ABSNO2(19)*(XNO2I(NXDIFF+1,NZ)+XNO2I(NXDIFF,
     1NZ))/2.+ALOG(CONT2+1.)
C
C  ADD OPTICAL DEPTH FOR BACKGROUND AIR IN PLUME
C
      TAUTOT=TAUTOT+XALONG*BTABAC(19)
C
C  STOP CALCULATION IF VISUAL RANGE EXCEEDED
C
      IF(TAUTOT.GT.3.912)GO TO 1160
      IF(NXX.LT.NXIN)GO TO 1120
```

```
C ************************************************************************

C
C  DETERMINE DISTANCE FROM BACKSIDE OF PLUME TO VISUAL RANGE LIMIT
C
      DELRV=(3.912-TAUTOT)/BTABAC(19)
C
C CALCULATE VISUAL RANGE
C
      IF(NROBJ.GT.1)GO TO 1130
      RV=(DIST(NX)-DIST(NXX1))/1000.+DELRV
      GO TO 1170
1130  CONTINUE
      RV=ROBJ(NR1)*RVAMB+(DIST(NX)-DIST(NXX1))/1000.+DELRV
      GO TO 1170
1160  CONTINUE
C
C INTERPOLATE INTO PLUME TO GET VISUAL RANGE
C
      DELRV= (3.912-TAUT1)/(TAUTOT-TAUT1) *XALONG
      IF(NROBJ.GT.1)GO TO 1165
      RV=(DIST(NX)-DIST(NX+1-NXX))/1000.+DELRV
      GO TO 1170
1165  CONTINUE
      RV=ROBJ(NR1)*RVAMB+(DIST(NX)-DIST(NX+1-NXX))/1000.+DELRV
1170  CONTINUE
C
C REDUCTION IN VISUAL RANGE
C
      REDRV=((RVAMB-RV)/RVAMB)*100.
C
C DISTANCE WITHIN PLUME
C
      ALONG=(DIST(NX)-DIST(NXX1))/1000.
      IF(NROBJ.GT.1)GO TO 1180
      RR=0.
      GO TO 1190
1180  RR=ROBJ(NR1)
1190  WRITE(6,67)ALONG,RR,RV,REDRV,YCAP,VAL,X,Y,YCAPD,VALD,CONT2
     1,BRATIO,XD,YD,DELUV,DELAB
1200  CONTINUE
C
C CHECK IF AT END OF LOOP ON INDEX FOR SCATTERING ANGLES FOR
C THE PLUME-BASED CASE CALCULATIONS.
C
      IF(NT.LT.(NT2-1))GO TO 1001
1300  CONTINUE
1301  CONTINUE
 1000 CONTINUE
C
C PRINT THE SO4 AND NO3 FORMATION RATES FOR EACH PLUME PARCEL AT X,Z,T.
C
      DO 30020 NT=1,NX2
      WRITE(6,10)
      XKM=DIST(NT)/1000.
      WRITE(6,30010)XKM
30010 FORMAT(47H HISTORY OF PLUME PARCEL AT DOWNWIND DISTANCE =,F6.1,
     1 3H KM,//)
      WRITE(6,30011)
30011 FORMAT(4X,6HPARCEL,5X,5HLOCAL,5X,2X,
C ********************************************************************************
     1 34HSO2-TO-SO4= CONVERSION RATE (%/HR),5X,2X,
     1 34HNOX-TO-HNO3 CONVERSION RATE (%/HR))
      WRITE(6,30012) (ALT(NZ),NZ=1,6),(ALT(NZ),NZ=1,6)
30012 FORMAT(6X,3HAGE,7X,4HTIME,/,6X,4H(HR),10X,5X,6(2X,A4),5X,6(2X,A4),
     1 /)
      DO 30020 NX=1,NT
      DTIME=((DIST(NT)-DIST(NX))/U)/3600.
      TIMER=TIMEHR-DTIME
30013 IF(TIMER.GT.0.)GO TO 30014
      TIMER=TIMER+24.
      GO TO 30013
30014 CONTINUE
      ITIMER=INT(TIMER)*100+INT(AMOD(TIMER,1.)*60.)
      PLMAGE=(DIST(NX)/U)/3600.
      WRITE(6,30015) PLMAGE,ITIMER,(RSO2R(NX,NZ,NT),NZ=1,6),
     1 (RNOXR(NX,NZ,NT),NZ=1,6)
30015 FORMAT(5X,F5.1,6X,I4,2(5X,6F6.2))
30020 CONTINUE
      DO 50018 NX=1,16
50018 DIST(NX)=DIST(NX)/1000.
      WRITE(6,50001)
50001 FORMAT(1H1,55X,22HPLOT FILE VERIFICATION)
      IF(NC2.NE.2)GO TO 30025
C
C  WRITE OUT THE VISUAL IMPACT PARAMETERS FOR PLOTTING OF THE
C  RESULTS OF OBSERVER-BASED CALCULATIONS. PLT1 IS PERCENT REDUCTION
C  IN VISUAL RANGE, FOR THE 16 DOWNWIND POINTS.NN=1 FOR CLEAR
C  SKY BACKGROUND. NN=2 FOR WHITE BACKGROUND.  NN=3 FOR GRAY
C  BACKGROUND.  NN=4 FOR BLACK BACKGROUND.  PLT1 IS SET TO
C  ZERO FOR NN=2,3,4. PLT2 = BLUE-RED RATIO.  PLT3 = PLUME
C  CONTRAST AT 0.55 MICROMETER.  PLT4 = DELTA E(LAB).
C
      WRITE(7)((PLT1(NX,NN),NX=1,16),NN=1,4)
      WRITE(7)((PLT2(NX,NN),NX=1,16),NN=1,4)
      WRITE(7)((PLT3(NX,NN),NX=1,16),NN=1,4)
      WRITE(7)((PLT4(NX,NN),NX=1,16),NN=1,4)
      WRITE(6,50002)
50002 FORMAT(1H0,56X,19HOBSERVER-BASED DATA)
      WRITE(6,50003)
50003 FORMAT(1H0,5X,14HSKY BACKGROUND)
      WRITE(6,50004)(NN,NN=NX1,NX2)
50004 FORMAT(1H0,9X,2HNX,7X,16(5X,I2))
      WRITE(6,50005)(DIST(NX),NX=NX1,NX2)
50005 FORMAT(1H0,3X,13HDISTANCE (KM),2X,16(4X,I3))
      WRITE(6,50006)
50006 FORMAT(1H0,1X,19HREDUCTION OF VISUAL)
      WRITE(6,50007)(PLT1(NX,1),NX=NX1,NX2)
50007 FORMAT(1H ,5X,9HRANGE (%),6X,16(1X,F6.3))
      WRITE(6,50008)
50008 FORMAT(1H0,2X,14HBLUE-RED RATIO)
      WRITE(6,50009)(PLT2(NX,1),NX=NX1,NX2)
50009 FORMAT(1H ,20X,16(1X,F6.3))
      WRITE(6,50010)
50010 FORMAT(1H0,2X,17HPLUME CONTRAST AT)
      WRITE(6,50011)(PLT3(NX,1),NX=NX1,NX2)
50011 FORMAT(1H ,5X,12H0.55 MICRONS,3X,16(1X,F6.3))
      WRITE(6,50012)
50012 FORMAT(1H0,20HPLUME PERCEPTIBILITY)
```

```
C ************************************************************************

            WRITE(6,50013)(PLT4(NX,1),NX=1,NX2)
      50013 FORMAT(1H ,3X,15HDELTA E(L*A*B*),2X,16(1X,F6.3))
            WRITE(6,50014)
      50014 FORMAT(/,1H0,3X,16HWHITE BACKGROUND)
            WRITE(6,50004)(NN,NN=NX1,NX2)
            WRITE(6,50005)(DIST(NX),NX=NX1,NX2)
            WRITE(6,50006)
            WRITE(6,50007)(PLT1(NX,2),NX=NX1,NX2)
            WRITE(6,50008)
            WRITE(6,50009)(PLT2(NX,2),NX=NX1,NX2)
            WRITE(6,50010)
            WRITE(6,50011)(PLT3(NX,2),NX=NX1,NX2)
            WRITE(6,50012)
            WRITE(6,50013)(PLT4(NX,2),NX=NX1,NX2)
            WRITE(6,50015)
      50015 FORMAT(/,1H0,4X,15HGRAY BACKGROUND)
            WRITE(6,50004)(NN,NN=NX1,NX2)
            WRITE(6,50005)(DIST(NX),NX=NX1,NX2)
            WRITE(6,50006)
            WRITE(6,50007)(PLT1(NX,3),NX=NX1,NX2)
            WRITE(6,50008)
            WRITE(6,50009)(PLT2(NX,3),NX=NX1,NX2)
            WRITE(6,50010)
            WRITE(6,50011)(PLT3(NX,3),NX=NX1,NX2)
            WRITE(6,50012)
            WRITE(6,50013)(PLT4(NX,3),NX=NX1,NX2)
            WRITE(6,50016)
      50016 FORMAT(1H1,3X,16HBLACK BACKGROUND)
            WRITE(6,50004)(NN,NN=NX1,NX2)
            WRITE(6,50005)(DIST(NX),NX=NX1,NX2)
            WRITE(6,50006)
            WRITE(6,50007)(PLT1(NX,4),NX=NX1,NX2)
            WRITE(6,50008)
            WRITE(6,50009)(PLT2(NX,4),NX=NX1,NX2)
            WRITE(6,50010)
            WRITE(6,50011)(PLT3(NX,4),NX=NX1,NX2)
            WRITE(6,50012)
            WRITE(6,50013)(PLT4(NX,4),NX=NX1,NX2)
            IF(NC1.NE.1)GO TO 30030
      C
      C  VISUAL IMPACT PARAMETERS FOR PLOTTING OF THE RESULTS OF
      C  THE PLUME-BASED CALCULATIONS WITH THE DESIRED SCATTERING ANGLE
      C  DISTANCES, AND PLUME-OBSERVER GEOMETRY AS SPECIFIED IN THE
      C  PLUME-BASED CALCULATIONS FOR CLEAR SKY AND WHITE, GRAY, AND
      C  BLACK BACKGROUNDS.
      C
      30025 CONTINUE
            WRITE(8)((PLOT1(NX,NN),NX=1,16),NN=1,4)
            WRITE(8)((PLOT2(NX,NN),NX=1,16),NN=1,4)
            WRITE(8)((PLOT3(NX,NN),NX=1,16),NN=1,4)
            WRITE(8)((PLOT4(NX,NN),NX=1,16),NN=1,4)
            IF(NC2.NE.1)WRITE(6,50001)
            WRITE(6,50017)
      50017 FORMAT(1H0,57X,16HPLUME-BASED DATA)
            WRITE(6,50003)
            WRITE(6,50004)(NN,NN=NX1,NX2)
            WRITE(6,50005)(DIST(NX),NX=NX1,NX2)
            WRITE(6,50006)
```

```
C **********************************************************************

      WRITE(6,50007)(PLOT1(NX,1),NX=NX1,NX2)
      WRITE(6,50008)
      WRITE(6,50009)(PLOT2(NX,1),NX=NX1,NX2)
      WRITE(6,50010)
      WRITE(6,50011)(PLOT3(NX,1),NX=NX1,NX2)
      WRITE(6,50012)
      WRITE(6,50013)(PLOT4(NX,1),NX=NX1,NX2)
      WRITE(6,50014)
      WRITE(6,50004)(NN,NN=NX1,NX2)
      WRITE(6,50005)(DIST(NX),NX=NX1,NX2)
      WRITE(6,50006)
      WRITE(6,50007)(PLOT1(NX,2),NX=NX1,NX2)
      WRITE(6,50008)
      WRITE(6,50009)(PLOT2(NX,2),NX=NX1,NX2)
      WRITE(6,50010)
      WRITE(6,50011)(PLOT3(NX,2),NX=NX1,NX2)
      WRITE(6,50012)
      WRITE(6,50013)(PLOT4(NX,2),NX=NX1,NX2)
      WRITE(6,50015)
      WRITE(6,50004)(NN,NN=NX1,NX2)
      WRITE(6,50005)(DIST(NX),NX=NX1,NX2)
      WRITE(6,50006)
      WRITE(6,50007)(PLOT1(NX,3),NX=NX1,NX2)
      WRITE(6,50008)
      WRITE(6,50009)(PLOT2(NX,3),NX=NX1,NX2)
      WRITE(6,50010)
      WRITE(6,50011)(PLOT3(NX,3),NX=NX1,NX2)
      WRITE(6,50012)
      WRITE(6,50013)(PLOT4(NX,3),NX=NX1,NX2)
      WRITE(6,50016)
      WRITE(6,50004)(NN,NN=NX1,NX2)
      WRITE(6,50005)(DIST(NX),NX=NX1,NX2)
      WRITE(6,50006)
      WRITE(6,50007)(PLOT1(NX,4),NX=NX1,NX2)
      WRITE(6,50008)
      WRITE(6,50009)(PLOT2(NX,4),NX=NX1,NX2)
      WRITE(6,50010)
      WRITE(6,50011)(PLOT3(NX,4),NX=NX1,NX2)
      WRITE(6,50012)
      WRITE(6,50013)(PLOT4(NX,4),NX=NX1,NX2)
30030 CONTINUE
      ENDFILE 7
      ENDFILE 8
      STOP
      END
PROGRAM SIZE:   PROCEDURE - 047016    LINKAGE - 035730    STACK - 000062
0000 ERRORS [<MAIN  >FTN-REV18.2]
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BLOCK DATA

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       BLOCK DATA
       COMMON/MIESCT/ROG,SIGMA,NLAMB,LAMB(20),JX,IT,TT(200),DUM(20),
      1PDUM(20,50),DUMA(20),DUMG(20)
       COMMON/ MISC/ ABSNO2(39),SOLAR(39),RAD,FORPIN,OMZ(39),OMH(39)
      1,NTHETA,RFR,RFI
       COMMON/COLOR/YCAP,VAL,X,Y,YCAPD,VALD,XD,YD,DELUV,DELAB,
      1XBAR(39),YBAR(39),ZBAR(39),PI,CONT1,CONT2,CONT3,BRATIO
       REAL LAMB
       DATA LAMB / 0.35,0.40,0.45,0.50,0.55,0.60,0.65,0.70,0.75,11*0.0/
       DATA TT /0.,22.,45.,90.,135.,158.,180.,193*0./
       DATA NLAMB / 9 /
       DATA NTHETA / 7 /
       DATA ABSNO2 /1.58, 1.63,1.67,1.71,1.67, 1.63, 1.54, 1.45,
      1             1.36, 1.17, 1.06, 0.92, 0.80, 0.69, 0.61, 0.54,
      2             0.46, 0.39, 0.31, 0.26, 0.21, 0.18, 0.15, 0.12, 0.1,
      3             0.080, 0.063, 0.053, 0.041, 0.035, 0.029, 0.024,
      4             0.021, 0.017, 0.014, 0.010, 0.0068, 0.0034,0./
       DATA  SOLAR / 1163., 1124., 1121., 1423., 1730., 1740., 1659.,
      1 1801., 1998., 2059., 2040., 2042., 1959., 1941., 1879., 1838.,
      2 1839., 1785., 1731., 1704., 1712., 1716., 1699., 1640., 1635.,
      3 1602., 1570., 1544., 1511., 1466., 1456., 1427., 1402., 1369.,
      4 1344., 1314., 1290.,1260., 1235.   /
       DATA XBAR /  0.0000, 0.0014, 0.0042, 0.0143, 0.0435, 0.1344,
      1 0.2839, 0.3483, 0.3362, 0.2908, 0.1954, 0.0956, 0.0320,
      2 0.0049, 0.0093, 0.0633, 0.1655, 0.2904, 0.4334, 0.5945, 0.7621,
      3 0.9163, 1.0263, 1.0622, 1.0026, 0.8544, 0.6424, 0.4479, 0.2835,
      4 0.1649, 0.0874, 0.0468, 0.0227, 0.0114, 0.0058, 0.0029, 0.0014,
      5 0.0007, 0.0003 /
       DATA YBAR / 0.0000, 0.0000, 0.0001, 0.0004, 0.0012, 0.0040,
      1 0.0116, 0.0230, 0.0380, 0.0600,0.0910, 0.1390, 0.2080, 0.3230,
      2 0.5030, 0.7100, 0.8620, 0.9540, 0.9950, 0.9950, 0.9520, 0.8700,
      3 0.7570,0.6310, 0.5030, 0.3810, 0.2650, 0.1750, 0.1070, 0.0610,
      4 0.0320, 0.0170, 0.0082, 0.0041, 0.0021, 0.0010, 0.0005, 0.0002,
      5 0.0001   /
       DATA ZBAR / 0.0000, 0.0065, 0.0201, 0.0679, 0.2074, 0.6456,
      1 1.3856, 1.7471, 1.7721, 1.6692, 1.2876, 0.8130, 0.4652, 0.2720,
      2 0.1582, 0.0782, 0.0422, 0.0203, 0.0087, 0.0039, 0.0021, 0.0017,
      3 0.0011, 0.0008, 0.0003, 0.0002, 13*0.0000 /
       END
PROGRAM SIZE:   PROCEDURE - 000000    LINKAGE - 000000    STACK - 000000
0000 ERRORS [<.DATA.>FTN-REV18.2]
```

FUNCTION ERF(XX)

```
      FUNCTION ERF(XX)
C
C  ERF=2/SQRT(PI)*INTEGRAL OF EXP(-T*T) FROM 0 TO X.
C  USING AN APPROXIMATION DUE TO HASTINGS  GOOD TO SEVEN SI
C  USING AN APPROXIMATION DUE TO HASTINGS. ABSOLUTE ERROR ABOUT 3E-7
C
      DIMENSION A(6)
      DATA A/.0000430638,.0002765672,.0001520143,.0092705272,.0422820123
     1,.0705230784 /
      X=ABS(XX)
      T=A(1)*X
      DO 10 I=2,6
      T=(T+A(I))*X
   10 CONTINUE
      T=1./(T+1.)
      ERF=1.-T**16
      IF(XX.LT.0.)ERF=-ERF
      RETURN
      END
PROGRAM SIZE:    PROCEDURE - 000114    LINKAGE - 000050    STACK - 000050
0000 ERRORS [<ERF    >FTN-REV18.2]
```

SUBROUTINE PERDIF(SPECR,ZENITH)

```
      SUBROUTINE PERDIF(SPECR,ZENITH)
C*****
C*****  CALCULATE PERFECT DIFFUSE REFLECTOR PROPERTIES
C*****
      COMMON/REF/XCAP0,YCAP0,ZCAP0,U0,V0,PROP
      COMMON/COLOR/YCAP,VAL,X,Y,YCAPD,VALD,XD,YD,DELUV,DELAB,
     1XBAR(39),YBAR(39),ZBAR(39),PI,CONT1,CONT2,CONT3,BRATIO
      DIMENSION SPECR(39)
      PI = 3.1415962
      XLUMIN=1./(2.*PI)
      CALL BACOBJ(ZENITH,0.,90.,4,0.,SPECR,XLUMIN)
      XCAP0=0.
      YCAP0=0.
      ZCAP0=0.
      DO 10 I=1,39
      XCAP0=XCAP0+SPECR(I)*XBAR(I)
      YCAP0=YCAP0+SPECR(I)*YBAR(I)
      ZCAP0=ZCAP0+SPECR(I)*ZBAR(I)
C     WRITE(6,101)XCAP0,YCAP0,ZCAP0
  101 FORMAT(3(2X,E10.4))
   10 CONTINUE
      PROP=100./YCAP0
      XCAP0=XCAP0*PROP
      YCAP0=100.
      ZCAP0=ZCAP0*PROP
      D0=XCAP0+1500.+3.*ZCAP0
      U0=4.*XCAP0/D0
      V0=900./D0
      RETURN
      END
PROGRAM SIZE:  PROCEDURE - 000244    LINKAGE - 000054    STACK - 000056
0000 ERRORS [<PERDIF>FTN-REV18.2]
```

SUBROUTINE CHROMA(SPECB,SPECR)

```
      SUBROUTINE CHROMA(SPECB,SPECR)
C*****
C***** CALCULATES VARIOUS COLORATION PARAMETERS SUCH AS CHROMA-
C***** TICITY COORDINATES,LUMINANCE,VALUE,CONTRAST,BLUE-RED RATIO,
C***** AND DELTA E.
C*****
      COMMON/COLOR/YCAP,VAL,X,Y,YCAPD,VALD,XD,YD,DELUV,DELAB,
     1XBAR(39),YBAR(39),ZBAR(39),PI,CONT1,CONT2,CONT3,BRATIO
      COMMON/REF/XCAP0,YCAP0,ZCAP0,U0,V0,PROP
      DIMENSION SPECB(39),SPECR(39)
      XCAP=0.
      YCAP=0.
      ZCAP=0.
      XCAPR=0.
      YCAPR=0.
      ZCAPR=0.
      DO 10 I=1,39
      XCAP=XCAP+SPECB(I)*XBAR(I)
      YCAP=YCAP+SPECB(I)*YBAR(I)
      ZCAP=ZCAP+SPECB(I)*ZBAR(I)
      XCAPR=XCAPR+SPECR(I)*XBAR(I)
      YCAPR=YCAPR+SPECR(I)*YBAR(I)
      ZCAPR=ZCAPR+SPECR(I)*ZBAR(I)
 10   CONTINUE
      XCAP=XCAP*PROP
      YCAP=YCAP*PROP
      ZCAP=ZCAP*PROP
      TXYZ=XCAP+YCAP+ZCAP
      XCAPR=XCAPR*PROP
      YCAPR=YCAPR*PROP
      ZCAPR=ZCAPR*PROP
      TXYZR=XCAPR+YCAPR+ZCAPR
      X=XCAP/TXYZ
      Y=YCAP/TXYZ
      XR=XCAPR/TXYZR
      YR=YCAPR/TXYZR
      XD=X-XR
      YD=Y-YR
      YCAPD=YCAP-YCAPR
      D=XCAP+15.*YCAP+3.*ZCAP
      DR=XCAPR+15.*YCAPR+3.*ZCAPR
      U=4.*XCAP/D
      V=9.*YCAP/D
      UR=4.*XCAPR/DR
      VR=9.*YCAPR/DR
C     WRITE(6,666)SPECB(4),SPECB(19),SPECB(34),SPECR(4),SPECR(19),
C    1SPECR(34)
C 666 FORMAT(/,3(1X,E13.4),/,3(1X,E13.4))
      CONT1=(SPECB(4)-SPECR(4))/SPECR(4)
      CONT2=(SPECB(19)-SPECR(19))/SPECR(19)
      CONT3=(SPECB(34)-SPECR(34))/SPECR(34)
      BRATIO=(SPECB(4)/SPECR(4))/(SPECB(34)/SPECR(34))
      VAL=116.*(YCAP/YCAP0)**.333-16.
      VALR=116.*(YCAPR/YCAP0)**.333-16.
      USTAR=13.*VAL*(U-U0)
      USTARR=13.*VALR*(UR-U0)
      VSTAR=13.*VAL*(V-V0)
      VSTARR=13.*VALR*(VR-V0)
```

```
          ASTAR=500.*((XCAP/XCAP0)**.333-(YCAP/YCAP0)**.333)
          ASTARR=500.*((XCAPR/XCAP0)**.333-(YCAPR/YCAP0)**.333)
          BSTAR=200.*((YCAP/YCAP0)**.333-(ZCAP/ZCAP0)**.333)
          BSTARR=200.*((YCAPR/YCAP0)**.333-(ZCAPR/ZCAP0)**.333)
          VALD=VAL-VALR
          USTARD=USTAR-USTARR
          VSTARD=VSTAR-VSTARR
          ASTARD=ASTAR-ASTARR
          BSTARD=BSTAR-BSTARR
          DELUV=SQRT(VALD*VALD+USTARD*USTARD+VSTARD*VSTARD)
          DELAB=SQRT(VALD*VALD+ASTARD*ASTARD+BSTARD*BSTARD)
          RETURN
          END
PROGRAM SIZE:   PROCEDURE - 001074    LINKAGE - 000174    STACK - 000064
0000 ERRORS [<CHROMA>FTN-REV18.2]
```

FUNCTION SYTVA(I,X)

```
        FUNCTION SYTVA(I,X)
        REAL A(6),B(6),C(6),D(6),LOGX
        DATA A/-.04054,-.04092,-.02536,-.02398,-.01837,-.01766/
        DATA B/.4871,.4745,.3092,.2857,.2165,.2022/
        DATA C/-1.16,-1.108,-.5988,-.5402,-.3099,-.2681/
        DATA D/2.057,1.993,1.497,1.459,1.217,1.174/
        LOGX=ALOG10(X)
        SYTVA=10.**(A(I)*LOGX*LOGX*LOGX+B(I)*LOGX*LOGX+C(I)*LOGX+D(I))
        RETURN
        END
PROGRAM SIZE:   PROCEDURE - 000064    LINKAGE - 000110    STACK - 000054
0000 ERRORS [<SYTVA >FTN-REV18.2]
```

FUNCTION SZTVA(I,X)

```
      FUNCTION SZTVA(I,X)
      REAL A(6),B(6),C(6),D(6),LOGX
      DATA A/-.04057,-.02174,-.01092,.002771,.006483,.009586/
      DATA B/.4847,.2555,.1266,-.03534,-.08176,-.1183/
      DATA C/-1.149,-.4799,-.1457,.369,.5107,.6285/
      DATA D/2.027,1.382,1.09,.5842,.4429,.3116/
      LOGX=ALOG10(X)
      SZTVA=10.**(A(I)*LOGX*LOGX*LOGX+B(I)*LOGX*LOGX+C(I)*LOGX+D(I))
      RETURN
      END
PROGRAM SIZE:   PROCEDURE - 000064    LINKAGE - 000110    STACK - 000054
0000 ERRORS [<SZTVA >FTN-REV18.2]
```

FUNCTION SYPAS(I,X)

```
      FUNCTION SYPAS(I,X)
C
C    PASQUILL-GIFFORD HORIZONTAL DISPERSION COEFFICIENT (SIGMA Y)
C
      REAL A(7),B(7),C(7),D(7),LOGX
      DATA A/-.012280,-.02334,-.008289,-.0062276,-.009115,-.0032318,0./
      DATA B/.00028741,.028256,-.0022985,-.0056984,-.0017835,-.011057,0.
     1/
      DATA C/.89182,.91347,.91977,.92394,.92826,.92159,0./
      DATA D/2.3237,2.1556,2.0142,1.8288,1.7006,1.5289,0./
      IF(I.EQ.7) GO TO 1
      LOGX=ALOG10(X/1000.)
      SYPAS=10.**(A(I)*LOGX*LOGX*LOGX+B(I)*LOGX*LOGX+C(I)*LOGX+D(I))
      RETURN
    1 LOGX=ALOG10(X)
      SYPAS=10.**(-.0020555*LOGX*LOGX*LOGX-.014857*LOGX*LOGX+1.0648*
     1LOGX-1.6212)
      RETURN
      END
PROGRAM SIZE:   PROCEDURE - 000170    LINKAGE - 000120    STACK - 000056
0000 ERRORS [<SYPAS >FTN-REV18.2]
```

FUNCTION SZPAS(I,X)

```
      FUNCTION SZPAS(I,X)
C
C   PASQUILL-GIFFORD VERTICAL DISPERSION COEFFICIENT (SIGMA Z).
C
      REAL A(7),B(7),C(7),D(7),LOGX
      DATA A/1.157,-.031027,-.0045741,.011157,-.0005092,.0037608,0./
      DATA B/2.815,.050674,.0040771,-.093465,-.10332,-.12889,0./
      DATA C/3.316,1.0827,.92084,.72583,.67969,.65602,0./
      DATA D/2.804,2.0327,1.7824,1.4901,1.3284,1.1391,0./
      IF(I.EQ.7) GO TO 1
      LOGX=ALOG10(X/1000.)
      SZPAS=10.**(A(I)*LOGX*LOGX*LOGX+B(I)*LOGX*LOGX+C(I)*LOGX+D(I))
      RETURN
    1 LOGX=ALOG10(X)
      SZPAS=10.**(-.0086351*LOGX*LOGX*LOGX-.036447*LOGX*LOGX+1.1243*LOGX
     1-1.8981)
      RETURN
      END
PROGRAM SIZE:   PROCEDURE - 000170    LINKAGE - 000120    STACK - 000056
0000 ERRORS [<SZPAS >FTN-REV18.2]
```

```
      SUBROUTINE INRAD(ZENITH)
C
C   CALCULATE OPTICAL PROPERTIES OF BACKGROUND ATMOSPHERE AND FOUR
C   AEROSOL MODES
C
      REAL LAMB
      COMMON/BCKGND/ ELEV,RVAMB,ACCAMB,AMBNO2,RH,ROVA,ROVC,ROVS,ROVP,
     1SIGA,SIGC,SIGS,SIGP,HPBL,IREAD,CORAMB,AMBNO3,AMBSO4,INTYP
     2,DENA,DENC,DENP,DENS,ROVCAR,SIGCAR,DENCAR,AMBCAR
      COMMON/MIESCT/ROG,SIGMA,NLAMB,LAMB(20),JX,IT,TT(200),DUM(20),
     1PDUM(20,50),DUMA(20),DUMG(20)
      COMMON/RADPRP/BTASO4(39),BTACOR(39),BTAPRM(39),BTAAER(39),
     1PAER(39,27),PPRIM(39,27),PSO4(39,27),PCOR(39,27),BTABAC(39)
     2,PCAR(39,27),ABSCAR(39),BTACAR(39),ABSSO4(39),ABSCOR(39),
     3 ABSPRM(39),GSO4(39),GCOR(39),GPRM(39),GCAR(39),GAER(39)
     4,GBAC(39),PBAC(39,27)
      COMMON / OPTDEP / TATOIZ(39),TATHIZ(39),TATOHZ(39),X1(39),
     1X2(39),TAUTDI(39),TAUTOD(39),XHDI(39),XHOD(39)
      COMMON/ MISC/ ABSNO2(39),SOLAR(39),RAD,FORPIN,OMZ(39),OMH(39)
     1,NTHETA,RFR,RFI
      COMMON/INDREF/RFRSO4,RFISO4,RFRCOR,RFICOR,RFRPRM,RFIPRM
     1,RFRCAR,RFICAR
      COMMON/DIFFI/FLUXUP(39),DIFIDN(39,21,41),DIFIUP(39,21,41)
      COMMON/DIFRAY/DIFRDN(9,21,41),DIFRUP(9,21,41)
      DIMENSION YMU(21),XAZ(21),
     2SUMT(39),GI(39),PPLM(39,27),SPECBI(39),SPECBU(39)
      DIMENSION DUMP(41),D(2)
      DIMENSION COEF(57),W(57)
      DIMENSION WINK(9),REL(9)
      DIMENSION OSO4(39),OCOR(39),OCAR(39),OAER(39)
      DIMENSION SPECRU(39),SPECRI(39)
      DATA WINK / 0. , 0.03 , 0.05 , 0.1 , 0.18 , 0.3 , 0.5,0.75 , 1. /
      DATA D / 0.,0. /
C     DATA YMU/1.0,0.9,0.8,0.7,0.6,0.5,0.4,0.3,0.2,0.1,0.0/
      DATA YMU/1.0,0.95,0.9,0.85,0.8,0.75,0.7,0.65,0.6,0.55,0.5,
     20.45,0.40,0.35,0.30,0.25,0.20,0.15,0.10,0.05,0.0/
C     DATA XAZ/0.,18.,36.,54.,72.,90.,108.,126.,144.,162.,180./
      DATA XAZ/0.,9.,18.,27.,36.,45.,54.,63.,72.,81.,90.,99.,108.,117.,
     2126.,135.,144.,153.,162.,171.,180./
      IREAD = 0
      TWOPI = 2.*3.141596
      FORPI = 2.*TWOPI
      FORPIN = 1./FORPI
      SQRTPI = SQRT(3.141596)
      SQR2PI = SQRTPI*SQRT(2.)
      HR = 9.8
      HA=3.5
      CONR = SQRT(2.*6356.*HR)
      CONA = SQRT(2.*6356.*HA)
      PARMA = CONA*SQRTPI*0.5
      PARMR = CONR*SQRTPI*0.5
      DX = SQRT(2.*6356.*HPBL)
      DR = DX/CONR
      DA = DX/CONA
C***  COMPUTE THE BACKGROUND RADIATIVE PROPERTIES
C*****
C*****
C*** GENERATE THE BSCAT TO MASS RATIOS AND THE PHASE FUNCTIONS
```

```
C*****
C*****
C***  ACCUMULATION MODE
C*****
      ROG = ROVA
      SIGMA = SIGA
      RFR = RFRSO4
      RFI = RFISO4
      DO 5 I = 1,39
    5 DUMP(I) = 0.36 + 0.01*FLOAT(I)
      IF(IREAD.EQ.1) GO TO 210
      CALL BSIZE
C     WRITE(6,6677)
C6677 FORMAT(/,2X,'TEST FOR CALL TO BSIZE',/)
      GO TO 250
  210 READ(5,1100) (    DUM(I),I=1,NLAMB)
      DO 220 I = 1,NLAMB
  220 READ(5,1200) (PDUM(I,J),J=1,NTHETA)
  250 CONTINUE
 1100 FORMAT(9F7.4)
 1200 FORMAT(7E11.4)
      CALL SPLNA (NLAMB,LAMB,DUM,2,D,COEF,W)
      DO 12 I = 1,39
      X = DUMP(I)
      DO 13 J = 2,NLAMB
13    IF(X.LE.LAMB(J)) GO TO 14
   14 Q = LAMB(J) - LAMB(J-1)
      Z = (X - LAMB(J-1))/Q
   12 BTASO4(I) =((Z*COEF(3*J-3)+COEF(3*J-4))*Z+COEF(3*J-5))*Z+DUM(J-1)
      DO 10 JT = 1,NTHETA
      DO 15 I = 1,NLAMB
   15 DUM(I) = PDUM(I,JT)
      CALL SPLNA (NLAMB,LAMB,DUM,2,D,COEF,W)
      DO 17 I = 1,39
      X = DUMP(I)
      DO 18 J = 2,NLAMB
18    IF(X.LE.LAMB(J)) GO TO 19
   19 Q = LAMB(J) - LAMB(J-1)
      Z = (X - LAMB(J-1))/Q
   17 PSO4(I,JT) =((Z*COEF(3*J-3)+COEF(3*J-4))*Z+COEF(3*J-5))*Z+DUM(J-1)
   10 CONTINUE
      DO 50 I=1,NLAMB
50    DUM(I)=DUMA(I)
      CALL SPLNA(NLAMB,LAMB,DUM,2,D,COEF,W)
      DO 53 I=1,39
         X=DUMP(I)
         DO 52 J=2,NLAMB
52          IF(X.LE.LAMB(J))GO TO 51
51       Q=LAMB(J)-LAMB(J-1)
         Z=(X-LAMB(J-1))/Q
53       ABSSO4(I)=((Z*COEF(3*J-3)+COEF(3*J-4))*Z+COEF(3*J-5))*Z+
     1 DUM(J-1)
      DO 150 I=1,NLAMB
  150 DUM(I)=DUMG(I)
      CALL SPLNA(NLAMB,LAMB,DUM,2,D,COEF,W)
      DO 151 I=1,39
      X=DUMP(I)
      DO 152 J=2,NLAMB
  152 IF(X.LE.LAMB(J)) GO TO 153
  153 Q=LAMB(J)-LAMB(J-1)
      Z=(X-LAMB(J-1))/Q
  151 GS04(I)=((Z*COEF(3*J-3)+COEF(3*J-4))*Z
     2+COEF(3*J-5))*Z+DUM(J-1)
C*****
C*****
C*****
C***  COARSE PARTICLE MODE
C*****
      ROG = ROVC
      SIGMA = SIGC
      RPR=RFRCOR
      RFI=RFICOR
      IF(IREAD.EQ.1) GO TO 310
      CALL BSIZE
C     WRITE(6,6678)
C6678 FORMAT(/,2X,'TEST2 FOR CALL TO BSIZE',/)
      GC TO 350
  310 READ(5,1100) (     DUM(I),I=1,NLAMB)
      DO 320 I = 1,NLAMB
  320 READ(5,1200) (PDUM(I,J),J=1,NTHETA)
  350 CONTINUE
      CALL SPLNA (NLAMB,LAMB,DUM,2,D,COEF,W)
      DO 22 I = 1,39
      X = DUMP(I)
      DO 23 J = 2,NLAMB
 23   IF(X.LE.LAMB(J)) GO TO 24
   24 Q = LAMB(J) - LAMB(J-1)
      Z = (X - LAMB(J-1))/Q
   22 BTACOR(I) =((Z*COEF(3*J-3)+COEF(3*J-4))*Z+COEF(3*J-5))*Z+DUM(J-1)
      DO 20 JT = 1,NTHETA
      DO 25 I = 1,NLAMB
 25   DUM(I) = PDUM(I,JT)
      CALL SPLNA (NLAMB,LAMB,DUM,2,D,COEF,W)
      DO 27 I = 1,39
      X = DUMP(I)
      DO 28 J = 2,NLAMB
 28   IF(X.LE.LAMB(J)) GO TO 29
   29 Q = LAMB(J) - LAMB(J-1)
      Z = (X - LAMB(J-1))/Q
   27 PCOR(I,JT) =((Z*COEF(3*J-3)+COEF(3*J-4))*Z+COEF(3*J-5))*Z+DUM(J-1)
   20 CONTINUE
      DO 60 I=1,NLAMB
 60   DUM(I)=DUMA(I)
      CALL SPLNA(NLAMB,LAMB,DUM,2,D,COEF,W)
      DO 63 I=1,39
         X=DUMP(I)
         DO 62 J=2,NLAMB
 62      IF(X.LE.LAMB(J))GO TO 61
 61      Q=LAMB(J)-LAMB(J-1)
         Z=(X-LAMB(J-1))/Q
 63   ABSCOR(I)=((Z*COEF(3*J-3)+COEF(3*J-4))*Z+COEF(3*J-5))*Z+DUM(J-1)
      DO 160 I=1,NLAMB
  160 DUM(I)=DUMG(I)
      CALL SPLNA(NLAMB,LAMB,DUM,2,D,COEF,W)
      DO 161 I=1,39
      X=DUMP(I)
```

SUBROUTINE INRAD(ZENITH)

```
      DO 162 J=2,NLAMB
  162 IF(X.LE.LAMB(J)) GO TO 163
  163 Q=LAMB(J)-LAMB(J-1)
      Z=(X-LAMB(J-1))/Q
  161 GCOR(I)=((Z*COEF(3*J-3)+COEF(3*J-4))*Z
     2+COEF(3*J-5))*Z+DUM(J-1)
C*****
C*** COMPUTE THE PRIMARY PARTICULATE PROPERTIES
C*****
      ROG = ROVP
      SIGMA = SIGP
      RFR=RFRPRM
      RFI=RFIPRM
      IF(IREAD.EQ.1) GO TO 410
      CALL BSIZE
C     WRITE(6,6679)
C6679 FORMAT(/,2X,'TEST3 FOR CALL TO BSIZE',/)
      GO TO 450
  410 READ(5,1100) (DUM(I),I=1,NLAMB)
      DO 420 I = 1,NLAMB
  420 READ(5,1200) (PDUM(I,J),J=1,NTHETA)
  450 CONTINUE
      CALL SPLNA (NLAMB,LAMB,DUM,2,D,COEF,W)
      DO 32 I = 1,39
      X = DUMP(I)
      DO 33 J = 2,NLAMB
   33 IF(X.LE.LAMB(J)) GO TO 34
   34 Q = LAMB(J) - LAMB(J-1)
      Z = (X - LAMB(J-1))/Q
   32 BTAPRM(I) =((Z*COEF(3*J-3)+COEF(3*J-4))*Z+COEF(3*J-5))*Z+DUM(J-1)
      DO 30 JT = 1,NTHETA
      DO 35 I = 1,NLAMB
   35 DUM(I) = PDUM(I,JT)
      CALL SPLNA (NLAMB,LAMB,DUM,2,D,COEF,W)
      DO 37 I = 1,39
      X = DUMP(I)
      DO 38 J = 2,NLAMB
   38 IF(X.LE.LAMB(J)) GO TO 39
   39 Q = LAMB(J) - LAMB(J-1)
      Z = (X - LAMB(J-1))/Q
   37 PPRIM(I,JT)=((Z*COEF(3*J-3)+COEF(3*J-4))*Z+COEF(3*J-5))*Z+DUM(J-1)
   30 CONTINUE
      DO 70 I=1,NLAMB
 70      DUM(I)=DUMA(I)
      CALL SPLNA(NLAMB,LAMB,DUM,2,D,COEF,W)
      DO 73 I=1,39
         X=DUMP(I)
         DO 72 J=2,NLAMB
 72      IF(X.LE.LAMB(J))GO TO 71
 71      Q=LAMB(J)-LAMB(J-1)
         Z=(X-LAMB(J-1))/Q
 73      ABSPRM(I)=((Z*COEF(3*J-3)+COEF(3*J-4))*Z+COEF(3*J-5))*Z+
     1   DUM(J-1)
      DO 170 I=1,NLAMB
  170 DUM(I)=DUMG(I)
      CALL SPLNA(NLAMB,LAMB,DUM,2,D,COEF,W)
      DO 171 I=1,39
      X=DUMP(I)
      DO 172 J=2,NLAMB
  172 IF(X.LE.LAMB(J)) GO TO 173
  173 Q=LAMB(J)-LAMB(J-1)
      Z=(X-LAMB(J-1))/Q
  171 GPRM(I)=((Z*COEF(3*J-3)+COEF(3*J-4))*Z
     2+COEF(3*J-5))*Z+DUM(J-1)
C
C     COMPUTE THE CARBON AEROSOL PROPERTIES.  FIRST
C     DO THE SCATTERING COEFFICIENT, THEN PHASE FUNCTION FOR
C     CARBON SCATTERING, THEN THE ABSORPTION
C     COEFFICIENT FOR CARBON.
C
      ROG=ROVCAR
      SIGMA=SIGCAR
      RFR = RFRCAR
      RFI = RFICAR
      CALL BSIZE
C     WRITE(6,6680)
C6680 FORMAT(/,2X,'TEST4 FOR CALL TO BSIZE',/)
      CALL SPLNA(NLAMB,LAMB, DUM, 2,D, COEF,W)
      DO 612 I=1,39
        X=DUMP(I)
        DO 613 J=2,NLAMB
613         IF(X.LE.LAMB(J))GO TO 614
614     Q=LAMB(J)-LAMB(J-1)
        Z=(X-LAMB(J-1))/Q
612     BTACAR(I)=((Z*COEF(3*J-3)+COEF(3*J-4))*Z+COEF(3*J-5))*Z+DUM(J-1
     1   )
      DO 610 JT=1,NTHETA
        DO 615 I=1,NLAMB
615         DUM(I)=PDUM(I,JT)
        CALL SPLNA(NLAMB,LAMB,DUM,2,D,COEF,W)
        DO 617 I=1,39
            X=DUMP(I)
            DO 618 J=2,NLAMB
618            IF(X.LE.LAMB(J))GO TO 619
619         Q=LAMB(J)-LAMB(J-1)
            Z=(X-LAMB(J-1))/Q
617         PCAR(I,JT)=((Z*COEF(3*J-3)+COEF(3*J-4))*Z+COEF(3*J-5))*Z+DUM
     1      (J-1)
610         CONTINUE
C
C     NEXT DO ABSORPTION DUE TO CARBON
C     DUMA= ABS/VTOT, DUMA F(WAVELENGTH ONLY)
C
      CALL SPLNA(NLAMB,LAMB,DUMA,2,D,COEF,W)
      DO 620 I=1,39
        X=DUMP(I)
        DO 625 J=2,NLAMB
625         IF(X.LE.LAMB(J))GO TO 624
624     Q=LAMB(J)-LAMB(J-1)
        Z=(X-LAMB(J-1))/Q
620     ABSCAR(I)=((Z*COEF(3*J-3)+COEF(3*J-4))*Z+COEF(3*J-5))*Z+DUMA(J-
     2  1)
      DO 180 I=1,NLAMB
 180  DUM(I)=DUMG(I)
      CALL SPLNA(NLAMB,LAMB,DUM,2,D,COEF,W)
      DO 181 I=1,39
      X=DUMP(I)
      DO 182 J=2,NLAMB
  182 IF(X.LE.LAMB(J)) GO TO 183
  183 Q=LAMB(J)-LAMB(J-1)
      Z=(X-LAMB(J-1))/Q
  181 GCAR(I)=((Z*COEF(3*J-3)+COEF(3*J-4))*Z
     2+COEF(3*J-5))*Z+DUM(J-1)
C*****
C*** ADJUST FOR THE RELATIVE HUMIDITY
C*****
      DO 41 I = 1,9
   41 REL(I) = 0.1*FLOAT(I-1)
      CALL SPLNA(9,REL,WINK,2,D,COEF,W)
      DO 42 I = 2,9
   42 IF(RH.LE.REL(I)) GO TO 43
   43 Z = (RH-REL(I-1))*10.
      FH = ((Z*COEF(3*I-3)+COEF(3*I-4))*Z+COEF(3*I-5))*Z+WINK(I-1)
      FACT =  1. + (0.85*FH)/(1.-RH) /DENA
      DO 40 I = 1,39
   40 BTASO4(I) = BTASO4(I)*FACT
C*****
C***  DETERMINE THE TYPE OF INPUT AND COMPUTE THE BACKGROUND RADIATIVE
C***  PROPERTIES.  INTYP = 1 MEANS THE NO3,SO4,COARSE MODE LEVEELS ARE
C***  SPECIFIED IN UGM/M3.  INTYPE = 2 MEANS THE VISUAL RANGE AND
C***  THE ACCUMULATION MODE ARE SPECIFIED IN KM-1 AND UGM/M3
C*****
      DENSO4=DENA
      DENNO3=DENA
      DENCOR=DENC
      WAVE = 0.55
      WV2 = (1./WAVE)**2
      WV4 = WV2*WV2
      TAR0IZ = 0.008569*WV4*(1. +0.0113*WV2+0.00013*WV4)*EXP(-ELEV/HR)
      RAY = TAR0IZ/HR
      IF(INTYP.EQ.2) GO TO 500
      IF(INTYP.NE.1) RETURN
      DO 460 I = 1,39
      X8 = BTASO4(I)*(AMBSO4/DENS + AMBNO3/DENS)
      X9 = BTACOR(I)*CORAMB/DENC
      X10 = BTACAR(I)*AMBCAR/DENCAR
      BTAAER(I) = (X8+X9+X10)*1.E-03
      IF(BTAAER(I).NE.0.) GO TO 458
      X8=0.
      X9=0.
      X10=0.
      GO TO 459
 458  CONTINUE
 459  CONTINUE
      OSO4(I)=(BTASO4(I)-ABSSO4(I))/BTASO4(I)
      OCOR(I)=(BTACOR(I)-ABSCOR(I))/BTACOR(I)
      OCAR(I)=(BTACAR(I)-ABSCAR(I))/BTACAR(I)
      SIG8=OSO4(I)*X8
      SIG9=OCOR(I)*X9
      SIG10=OCAR(I)*X10
      SIGAR=(X8+X9+X10)*1.E-03
      OAER(I)=SIGAR/BTAAER(I)
      GAER(I) = (GSO4(I)*SIG8+GCOR(I)*SIG9+GCAR(I)*SIG10)*1.E-03
     2 /SIGAR
```

```
      DO 460 J = 1,NTHETA
  460 PAER(I,J)=(PSO4(I,J)*SIG8+PCOR(I,J)*SIG9+PCAR(I,J)*SIG10)*1.E-03
     1 /SIGAR
      SIGKOS = RAY + BTAAER(19) + ABSNO2(19)*AMBNO2
      RVAMB = -ALOG(.02)/SIGKOS
      GO TO 600
  500 CONTINUE
C*****
C***  DETERMINE THE MASS OF THE ACCUMULATION MODE
C*****
      SIGKOS = -ALOG(.02)/RVAMB
      SIGINT = BTACOR(19)*CORAMB*1.E-03/DENC + RAY + ABSNO2(19)*AMBNO2
     1 + BTACAR(19)*AMBCAR*1.E-03/DENCAR
      IF(SIGKOS-SIGINT) 100,100,120
  100 AMBSO4 = 0.
      CORAMB = (SIGKOS-RAY-ABSNO2(19)*AMBNO2-AMBCAR*BTACAR(19)
     1 *1.E-03/DENCAR)/(BTACOR(19)*1.E-03/DENC)
      IF(CORAMB.LT.0.) PRINT 2000
 2000 FORMAT(1H ,44HTROUBLE WITH THE CONCENTRATION SPECIFICATION)
      GO TO 1150
  120 AMBSO4 = (SIGKOS - SIGINT)/(BTASO4(19)*1.E-03/DENS)
 1150 CONTINUE
      DO 1160 I = 1,39
      X8 = BTASO4(I)*(AMBSO4/DENS+AMBNO3/DENS)
      X9 = BTACOR(I)*CORAMB/DENC
      X10 = BTACAR(I)*AMBCAR/DENCAR
      BTAAER(I) =(X8 + X9 + X10)*1.E-03
      OSO4(I)=(BTASO4(I)-ABSSO4(I))/BTASO4(I)
      OCOR(I)=(BTACOR(I)-ABSCOR(I))/BTACOR(I)
      OCAR(I)=(BTACAR(I)-ABSCAR(I))/BTACAR(I)
      SIG8=OSO4(I)*X8
      SIG9=OCOR(I)*X9
      SIG10=OCAR(I)*X10
      SIGAR=(SIG8+SIG9+SIG10)*1.E-03
      OAER(I)=SIGAR/BTAAER(I)
      DO 2160 J = 1,NTHETA
 2160 PAER(I,J) = (PSO4(I,J)*SIG8+PCOR(I,J)*SIG9+PCAR(I,J)*SIG10)*1.E-03
     1 /SIGAR
      GAER(I) = (GSO4(I)*SIG8+GCOR(I)*SIG9+GCAR(I)*SIG10)*1.E-03
     2 /SIGAR
C     WRITE(6,2345) GAER(I)
 2345 FORMAT(2X,E13.4)
 1160 CONTINUE
      AMBNO3 = 0.
  600 CONTINUE
C*****
C***  COMPUTE THE VERTICAL AND HORIZONTAL OPTICAL DEPTHS
C*****
      DO 200 I = 1,39
      WAVE = 0.36 + FLOAT(I)*0.01
      WV2 = WAVE**(-2)
      WV4 = WV2*WV2
      TAR0IZ = 0.008569*WV4*(1. + 0.0113*WV2 + 0.00013*WV4)*EXP(-ELEV/
     1HR)
      TAA0IZ = BTAAER(I)*HA
      TAT0IZ(I) = TAR0IZ + TAA0IZ
      TARHIZ = TAR0IZ*EXP(-HPBL/HR)
      TAR0HZ = TAR0IZ - TARHIZ
      TAAHIZ = TAAOIZ*EXP(-HPBL/HA)
      TATHIZ(I) = TARHIZ + TAAHIZ
      TATOHZ(I) = TATOIZ(I) - TATHIZ(I)
      BETAOR = TAROIZ/HR
      BTABAC(I) = BTAAER(I) + BETAOR + ABSNO2(I)*AMBNO2
      TAAOHZ=TAAOIZ-TAAHIZ
      X1(I)=TARHIZ/(TAAHIZ*OAER(I)+TARHIZ)
      X2(I)=TAROHZ/(TAAOHZ*OAER(I)+TAROHZ)
C     COMPUTE THE HORIZONTAL PATH DEPTH
      TAUROI = BETAOR*PARMR
      TAUAOI = BTAAER(I)*PARMA
      TAUROD = BETAOR*ERF(DR)*PARMR
      TAUAOD = BTAAER(I)*ERF(DA)*PARMA
      TAURDI = TAUROI - TAUROD
      TAUADI = TAUAOI - TAUAOD
      TAUTOD(I) = TAUROD + TAUAOD
      TAUTDI(I) = TAURDI + TAUADI
      XHDI(I) = TAURDI/(TAURDI + TAUADI*OAER(I))
      XHOD(I) = TAUROD/(TAUROD + TAUAOD*OAER(I))
      GBAC(I) = GAER(I)*TAAOIZ/TATOIZ(I)
      DO 510 J=1,NTHETA
      PBAC(I,J)=(PAER(I,J)*TAAOIZ+PRAY*TAROIZ)/TATOIZ(I)
  510 CONTINUE
C     WRITE(6,2346)GBAC(I)
 2346 FORMAT(2X,E13.4)
C
C     ****** DIAGNOSTIC PRINT OUT *********
C
C     IF (I .NE. 19) GO TO 300
C     WRITE(6,260)
 260  FORMAT(1H ,5X,'TAROIZ, TAAOIZ, TATOIZ(19), TARHIZ, TAROHZ, TAAHIZ,
     1 TATHIZ(19), TATOHZ(19), BETAOR, BTABAC')
C     WRITE(6,261)TAROIZ,TAAOIZ,TATOIZ(19),TARHIZ,TAROHZ,TAAHIZ,
C    1 TATHIZ(19),TATOHZ(19),BETAOR,BTABAC(19)
 261  FORMAT(1H ,5X,10(E9.3,1X))
C     WRITE(6,262)
 262  FORMAT(1H ,5X,'TAAOHZ, X1(19), X2(19), OAER(19), TAUROI, TAUAOI, T
     1AUROD, TAUAOD, TAURDI, TAUADI')
C     WRITE(6,261)TAAOHZ,X1(19),X2(19),OAER(19),TAUROI,TAUAOI,TAUROD,
C    1 TAUAOD,TAURDI,TAUADI
C     WRITE(6,263)
 263  FORMAT(1H ,5X,'TAUTOD(19), TAUTDI(19), XHDI(19), XHOD(19)')
C     WRITE(6,261)TAUTOD(19),XHDI(19),XHOD(19)
C 300 CONTINUE
C
C     ***************************************
C
C***  ADJUST THE OPTICAL DEPTH FOR NO2
      TAAOHZ = TAAOIZ - TAAHIZ
      TATOIZ(I) = TAROIZ + TAAOIZ + ABSNO2(I)*AMBNO2*HPBL
      TATOHZ(I) = TATOIZ(I) - TATHIZ(I)
      TAUTOD(I) = TAUROD + TAUAOD + ABSNO2(I)*AMBNO2*DX
      OMZ(I) = (TAROHZ + TAAOHZ*OAER(I))/TATOHZ(I)
            IF(OMZ(I).GT.0.999) OMZ(I) = 0.999
      OMH(I) = (TAUROD + TAUAOD*OAER(I))/TAUTOD(I)
C*****
C***  CHANGE THE SCATTERING COEFICIENTS FROM BSCAT/VOL TO BSCAT/MASS
C***
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        BTASO4(I) = BTASO4(I)*1.E-03/DENSO4
        BTAPRM(I) = BTAPRM(I)*1.E-03/DENP
        BTACOR(I) = BTACOR(I)*1.E-03/DENC
C
C       CHANGE COEFFICIENTS FOR CARBON FROM BSCAT/VOL TO BSCAT/MASS.
C       CHANGE ABSORPTION COEFFICIENT FOR CARBON TO ABS/MASS.
C       CHANGE ABSORPTION COEFFICIENTS FOR SULFATE, COARSE
C       MODE AEROSOL, AND PRIMARY PARTICULATE FROM ABS/VOL
C       TO ABS/MASS.
C
        BTACAR(I)=BTACAR(I)*1.E-03/DENCAR
        ABSCAR(I)=ABSCAR(I)*1.E-03/DENCAR
        ABSSO4(I)=ABSSO4(I)*1.E-03/DENSO4
        ABSCOR(I)=ABSCOR(I)*1.E-03/DENC
        ABSPRM(I)=ABSPRM(I)*1.E-03/DENP
C
C      ****************** DIAGNOSTIC PRINT OUT ****************
C
C        IF(I.NE.19)GO TO 355
C       WRITE(6,264)
264     FORMAT(1H ,5X,'TAA0HZ, TATOIZ(19), TATOHZ(19), TAUTOD(19), OMZ(19)
       1, OMH(19), BTASO4(19), BTAPRM(19), BTACOR(19), BTACAR(19)')
C       WRITE(6,261)TAA0HZ,TATOIZ(19),TATOHZ(19),TAUTOD(19),OMZ(19),
C      1 OMH(19),BTASO4(19),BTAPRM(19),BTACOR(19),BTACAR(19)
C       WRITE(6,265)
265     FORMAT(1H ,5X,'ABSCAR(19), ABSSO4(19), ABSCOR(19), ABSPRM(19)')
C       WRITE(6,261)ABSCAR(19),ABSSO4(19),ABSCOR(19),ABSPRM(19)
C355    CONTINUE
C
C     ******************************************
C
    200 CONTINUE
C       WRITE(6,958)
    958 FORMAT(/,3X,'TEST BEFORE CALL BACCLI AND RAYREI',/)
        PI=3.14159
        RAD=PI/180.
C
C       COMPUTE DOWNWARD AND UPWARD INTENSITIES
C
        U0=COS(ZENITH*RAD)
        DO 55 J=1,21
        U=YMU(J)
C       BETA=ASIN(U)/RAD
        DO 55 K=1,21
        DD=XAZ(K)
C       THETA=ACOS(U*U0*COS(DD)+SQRT(1.-U**2)*SQRT(1.-U0**2))/RAD
        CALL BACCLI(U,U0,DD,SPECBI,SPECBU)
        CALL RAYREI(U,U0,DD,SPECRI,SPECRU)
        DO 55 I=1,9
        DIFIUP(I,J,K)=SPECBU(I)
        DIFIDN(I,J,K)=SPECBI(I)
        DIFRUP(I,J,K)=SPECRU(I)
        DIFRDN(I,J,K)=SPECRI(I)
C       WRITE(6,6)U,DD,I,DIFIDN(I,J,K),DIFIUP(I,J,K)
C     6 FORMAT(/,2(2X,E13.4),I5,2(2X,E13.4))
     55 CONTINUE
        RETURN
        END
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SUBROUTINE RAYREF(ZENITH,BETA,THETA,ITHETA,SPECR)

```
      SUBROUTINE RAYREF(ZENITH,BETA,THETA,ITHETA,SPECR)
C
C CALCULATE SPECTRAL RADIANCE OF CLEAR SKY IN A RAYLEIGH ATMOSPHERE.
C
      COMMON/BCKGND/ ELEV,RVAMB,ACCAMB,AMBNO2,RH,ROVA,ROVC,ROVS,ROVP,
     1SIGA,SIGC,SIGS,SIGP,HPBL
      COMMON / MISC / ABSNO2(39),SOLAR(39),RAD, FORPIN
      DIMENSION SPECR(39)
      DIMENSION GI(39)
      TWOPI = .5/FORPIN
      RHO = .3
      RHOPI = 0.5*RHO*TWOPI
      XMU0 = COS(RAD*ZENITH)
      XMU = SIN(RAD*BETA)
      PRAY = 0.75*(1.+COS(RAD*THETA)**2)
      HR = 9.8
      CONR = SQRT(2.*6356.*HR)
      SQRTPI = SQRT(3.1415962)
      PARMR = CONR*SQRTPI*0.5
      DX = SQRT(2.*6356.*HPBL)
      DRR = DX/CONR
      IPF=2
      XMUR=SIN(BETA*RAD)
      XMU0=COS(ZENITH*RAD)
      COSTTA=COS(THETA*RAD)
      IF(BETA.EQ.90.)GO TO 30
      CDR=(COSTTA-XMUR*XMU0)/(SQRT(1.-XMU0**2)*
     2SQRT(1.-XMUR**2))
      GO TO 31
   30 IF(THETA.NE.ZENITH)GO TO 60
      DF=0.
      GO TO 32
   31 CONTINUE
      ACDR=ABS(CDR)
      IF(ACDR.GT.1.) GO TO 60
      DF=ACOS(CDR)/RAD
   32 CONTINUE
C     WRITE(6,64)BETA,DF,THETA
      CALL INTEG(DF,BETA,IPF,GI)
      DO 50 I = 1,39
      WAVE = 0.36 + FLOAT(I)*0.01
      WV2 = WAVE**(-2.)
      WV4 = WV2*WV2
      TAR0IZ = 0.008569*WV4*(1. + 0.0113*WV2 + 0.00013*WV4)*EXP(-ELEV/
     1HR)
      TARHIZ = TAR0IZ*EXP(-HPBL/HR)
      TAR0HZ = TAR0IZ - TARHIZ
      FD0 = SOLAR(I)*EXP(-TAR0IZ/XMU0)
      FDH = SOLAR(I)*EXP(-TARHIZ/XMU0)
      FDAV = (FD0 + FDH)*0.5
      IF(BETA.EQ.0.) GO TO 100
      SKY = FORPIN*PRAY*(1.-EXP(-TARHIZ/XMU))*SOLAR(I)
      SURF = SKY*EXP(-TAR0HZ/XMU) + FORPIN*PRAY*(1.-EXP(-TAR0HZ
     1/XMU0))*FDAV
      SPECR(I) = SURF + GI(I)
      GO TO 50
  100 CONTINUE
      BETA0R = TAR0IZ/HR
      TAUROI = BETAOR*PARMR
      TAUROD = BETAOR*ERF(DRR)*PARMR
      TAURDI = TAUROI - TAUROD
      SKYH = FORPIN*PRAY*(1.-EXP(-TAURDI))*SOLAR(I)
      SURFH = SKYH*EXP(-TAUROD) + FORPIN*PRAY*(1.-EXP(-TAUROD))
     1*FDAV
      SPECR(I) = SURFH + GI(I)
   50 CONTINUE
      GO TO 63
   60 DO 61 I=1,39
      SPECR(I)=1.
   61 CONTINUE
C     WRITE(6,64)BETA,CDR,THETA
C  64 FORMAT(/,3(X,E13.4))
C     WRITE(6,62)
C 62  FORMAT(/,' THIS THETA ANGLE IS IMPOSSIBLE ',/)
  63  RETURN
      END
PROGRAM SIZE:   PROCEDURE - 001126    LINKAGE - 000302    STACK - 000072
0000 ERRORS [<RAYREF>FTN-REV18.2]
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      SUBROUTINE RAYREI(U,U0,DD,SPECRI,SPECRU)
C
C CALCULATE SPECTRAL RADIANCE OF CLEAR SKY IN A RAYLEIGH ATMOSPHERE.
C
      COMMON/BCKGND/ ELEV,RVAMB,ACCAMB,AMBNO2,RH,ROVA,ROVC,ROVS,ROVP,
     1SIGA,SIGC,SIGS,SIGP,HPBL
      COMMON / MISC / ABSNO2(39),SOLAR(39),RAD, FORPIN
      DIMENSION SPECRI(39),SPECRU(39),FLUXUP(39)
      REAL I1,I2,K
      DATA PI/3.14159265358/
C
      DTR(X)=PI/180.*X
      RTD(X)=180./PI*X
C
      IF(U.LT.0.0262) U=0.0262
      A1=0.3
      W0=1.
      DO 50 II=1,9
      I=5*(II-2)+4
      IF(II.EQ.1)I=1
      WAVE = 0.36 + FLOAT(I)*0.01
      WV2 = WAVE**(-2.)
      WV4 = WV2*WV2
      T0 = 0.008569*WV4*(1. + 0.0113*WV2 + 0.00013*WV4)*EXP(-ELEV/
     19.8)
      F=SOLAR(I)/PI
C
      CALL RAYSCT(U,U0,DD,C1,C2,S,S1,P1,P2,W0,B0,B1,B2)
C
C     DEFINE CONSTANTS
C
      G1=2.*(1.-W0*(1.-B1))
      G2=2.*W0*B1
      K=G1**2-G2**2
      IF(K.LE.0) K=0.
      K=SQRT(G1*G1-G2*G2)
      C=PI*F*W0*(B0/U0-G2*(1.-B0)-G1*B0)*U0**2/(1.-K**2*U0**2)
      E1=(C*(G1+1./U0)-PI*F*W0*B0)*(1./(G1-K)-A1/G2)
      E2=-C+PI*F*U0*A1+A1/G2*(C*(G1+1./U0)-PI*F*W0*B0)
      E3=(G1+K)*(-1./(G1-K)+A1/G2)
      E4=1.-A1/G2*(G1+K)
      B=(E1*EXP(K*T0)+E2*EXP(-T0/U0))/(E3*EXP(K*T0)+E4*EXP(-K*T0))
      A=(B*(G1+K)+(C*(G1+1./U0)-PI*F*W0*B0))/(K-G1)
C
C     COMPUTE INTENSITIES
C
      U1=A*(W0/PI)*(1.-B2+B2/G2*(G1-K))
      U2=B*(W0/PI)*(1.-B2+B2/G2*(G1+K))
      U3=C*(W0/PI)*(1.-B2)+W0*B2/(PI*G2)*C*(G1+1./U0-PI*F*W0*B0)+F/4.*PI
C
      F5=A*EXP(K*T0)+B*EXP(-K*T0)+C*EXP(-T0/U0)
C
      D2=F5/A-U1*EXP(K*T0)/(1.-U*K)
      D3=-U2*EXP(-K/T0)/(1.+U*K)-U3*EXP(-T0/U)/(1.+U/U0)
      D1=EXP(-T0/U)*(D2+D3)
C
C     UPWARD INTENSITY
C
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```
      T=0.
      I1=D1*EXP(T/U)+U1*EXP(K*T)/(1.-U*K)+U2*EXP(-K*T)/(1.+U*K)
     1 +U3*EXP(-T/U0)/(1.+U/U0)
      FLUXUP(II)=A*EXP(K*T0) + B*EXP(-K*T0) + C*EXP(-T0/U0)
      SPECRU(II) = FLUXUP(II) / PI
C
C     DOWNWARD INTENSITY
C
      T=T0
      W1=W0/PI*A*(1.-U*K)/(1.+U*K)*(B2+(1.-B2)*(G1-K)/G2)
      W2=W0/PI*B*(1.+U*K)/(1.-U*K)*(B2+(1.-B2)*(G1+K)/G2)
      Y=C*(G1+1./U0)-PI*F*W0*B0
      W3=(U0+U)/(U0-U)*(W0/PI*B2*C+W0/PI*(1.-B2)*Y/G2+F/4.*P2)
      E1=-(W1/(1.-U*K)+W2/(1.+U*K)+W3/(1.+U/U0))
      SPECRI(II)=E1*EXP(-T/U)+W1*EXP(K*T)/(1.-U*K)+W2*EXP(-K*T)/(1.+U*K)
     1 +W3*EXP(-T/U0)/(1.+U/U0)
   50 CONTINUE
      GO TO 51
   51 RETURN
      END
PROGRAM SIZE:   PROCEDURE - 002074    LINKAGE - 000276    STACK - 000112
0000 ERRORS [<RAYREI>FTN-REV18.2]
```

SUBROUTINE RAYSCT(U,U0,D1,C1,C2,S,S1,P1,P2,W0,B0,B1,B2)

```
      SUBROUTINE RAYSCT(U,U0,D1,C1,C2,S,S1,P1,P2,W0,B0,B1,B2)
      DATA PI/3.141592653/
C
      DTR(X)=PI/180.*X
      RTD(X)=180./PI*X
C
      D=DTR(D1)
C
      C1=-U*U0+SQRT(1.-U*U)*SQRT(1.-U0*U0)*COS(D)
      C2=U*U0+SQRT(1.-U*U)*SQRT(1.-U0*U0)*COS(D)
      S=ACOS(-C2)
      S1=RTD(S)
      P1=.75*(1.+C1*C1)
      P2=.75*(1.+C2*C2)
      W0=.9999
      B2=.500005
      B1=.500005
      B0=.500005
C     WRITE(6,100)
C100  FORMAT(//,10X,'RAYLEIGH SCATTERING',//)
C     WRITE(6,105) S1
C105  FORMAT(2X,'SCATTERING ANGLE',1X,F12.6,1X,'DEG',//)
C     WRITE(6,110) P1,P2
C110  FORMAT(2X,'PUP',F12.6,1X,'PDOWN',F12.6)
      RETURN
      END
PROGRAM SIZE:   PROCEDURE - 000242    LINKAGE - 000032    STACK - 000130
0000 ERRORS [<RAYSCT>FTN-REV18.2]
```

SUBROUTINE BACCLN(ZENITH,BETA,THETA,ITHETA,SPECB)

```
      SUBROUTINE BACCLN(ZENITH,BETA,THETA,ITHETA,SPECB)
C
C    CALCULATE SPECTRAL RADIANCE OF CLEAR SKY OF GIVEN BACKGROUND ATMOS-
C    PHERE WITH NO2 AND FINE AND COARSE AEROSOL.
C
      COMMON/RADPRP/BTASO4(39),BTACOR(39),BTAPRM(39),BTAAER(39),
     1PAER(39,27),PPRIM(39,27),PSO4(39,27),PCOR(39,27),BTABAC(39)
     2,PCAR(39,27),ABSCAR(39),BTACAR(39),ABSSO4(39),ABSCOR(39),
     3 ABSPRM(39),GSO4(39),GCOR(39),GPRM(39),GCAR(39),GAER(39)
     4,GBAC(39),PBAC(39,27)
      COMMON/ OPTDEP / TATOIZ(39),TATHIZ(39),TATOHZ(39),X1(39),
     1X2(39),TAUTDI(39),TAUTOD(39),XHDI(39),XHOD(39)
      COMMON/ MISC/ ABSNO2(39),SOLAR(39),RAD,FOPPIN,OMZ(39),OMH(39)
     1,NTHETA,RFR,RFI
      DIMENSION SPECB(39),GI(39)
      TWOPI = 0.5/FORPIN
      RHO = .3
      RHOPI = 0.5*RHO*TWOPI
      XMU0 = COS(RAD*ZENITH)
      XMU = SIN(RAD*BETA)
      PRAY = 0.75*(1.+COS(RAD*THETA)**2)
      IF(BETA.EQ.0.) GO TO 100
      IPF = 0
      XMUR=SIN(BETA*RAD)
      XMU0=COS(ZENITH*RAD)
      COSTTA=COS(THETA*RAD)
      IF(BETA.EQ.90.)GO TO 30
      CDR=(COSTTA-XMUR*XMU0)/(SQRT(1.-XMU0**2)*
     2SQRT(1.-XMUR**2))
      GO TO 31
   30 IF(THETA.NE.ZENITH)GO TO 60
      DF=0.
      GO TO 32
   31 CONTINUE
      ACDR=ABS(CDR)
      IF(ACDR.GT.1.) GO TO 60
      DF=ACOS(CDR)/RAD
   32 CONTINUE
C     WRITE(6,64)BETA,DF,THETA
      CALL INTEG(DF,BETA,IPF,GI)
      DO 50 I = 1,39
      FD0 = SOLAR(I)*EXP(-TATOIZ(I)/XMU0)
      FDH = SOLAR(I)*EXP(-TATHIZ(I)/XMU0)
      FDAV = (FD0 + FDH)*0.5
      PTOTDI = X1(I)*PRAY + (1.-X1(I))*PAER(I,ITHETA)
      PTOTOD = X2(I)*PRAY + (1. - X2(I))*PAER(I,ITHETA)
      PTOTOD = PTOTOD*OMZ(I)
      SKY = FORPIN*PTOTDI*(1.-EXP(-TATHIZ(I)/XMU))*SOLAR(I)
      SURF = SKY*EXP(-TATOHZ(I)/XMU) + FORPIN*PTOTOD*(1.-EXP(-TATOHZ(I
     1)/XMU))*FDAV
      SPECB(I) = SURF + GI(I)*(1.-EXP(-TATOIZ(I)/XMU))
      TIOS = SPECB(I) / SOLAR(I)
      SSOS = SURFH    / SOLAR(I)
      DFOS = GI(I)    / SOLAR(I)
C     WRITE(6,44)I,BETA,DF,THETA,TIOS,SSOS,DFOS
   50 CONTINUE
      RETURN
  100 CONTINUE
```

SUBROUTINE BACCLN(ZENITH,BETA,THETA,ITHETA,SPECB)

```
C*****
C***  DO THE HORIZONTAL CASE
C*****
      IPF=0
      XMUR=SIN(BETA*RAD)
      XMU0=COS(ZENITH*RAD)
      COSTTA=COS(THETA*RAD)
      CDR=(COSTTA-XMUR*XMU0)/(SQRT(1.-XMU0**2)*
     2SQRT(1.-XMUR**2))
      ACDR=ABS(CDR)
      IF(ACDR.GT.1.) GO TO 60
      DF=ACOS(CDR)/RAD
C     WRITE(6,64)BETA,DF,THETA
      CALL INTEG(DF,BETA,IPF,GI)
      DO 75 I = 1,39
      FD0 = SOLAR(I)*EXP(-TAT0IZ(I)/XMU0)
      FDH = SOLAR(I)*EXP(-TATHIZ(I)/XMU0)
      FDAV = (FD0 + FDH)*0.5
      PTOTDI = PRAY*XHDI(I) + (1.-XHDI(I))*PAER(I,ITHETA)
      PTOTOD = XHOD(I)*PRAY + (1.-XHOD(I))*PAER(I,ITHETA)
      PTOTOD = PTOTOD*OMH(I)
      SKYH = FORPIN*PTOTDI*(1.-EXP(-TAUTDI(I)))*SOLAR(I)
      SURFH = SKYH*EXP(-TAUTOD(I)) + FORPIN*PTOTOD*(1.-EXP(-TAUTOD(I)))
     1*FDAV
      SPECB(I) = SURFH + GI(I)*(1.-EXP(-TAUTOD(I)-TAUTDI(I)))
      TIOS = SPECB(I) / SOLAR(I)
      SSOS = SURFH    / SOLAR(I)
      DFOS = GI(I)    / SOLAR(I)
C     WRITE(6,44)I,BETA,DF,THETA,TIOS,SSOS,DFOS
C  44 FORMAT(/,X,I5,3(X,E13.4),/,3(X,E13.4))
   75 CONTINUE
      GO TO 63
   60 DO 61 I=1,39
      SPECB(I)=1.
   61 CONTINUE
C     WRITE(6,64)BETA,CDR,THETA
C  64 FORMAT(/,3(X,E13.4))
C     WRITE(6,62)
C 62  FORMAT(/,' THIS THETA ANGLE IS NOT POSSIBLE ',/)
  63  RETURN
      END
PROGRAM SIZE:   PROCEDURE - 001424    LINKAGE - 000274    STACK - 000072
0000 ERRORS [<BACCLN>FTN-REV18.2]
```

SUBROUTINE INTEG(DF,BETA,IPF,GI)

```
      SUBROUTINE INTEG(DF,BETA,IPF,GI)
C
C       THIS SUBROUTINE CALCULATES THE DIFFUSE FIELD INTEGRAL
C
      COMMON/RADPRP/BTASO4(39),BTACOR(39),BTAPRM(39),BTAAER(39),
     1PAER(39,27),PPRIM(39,27),PSO4(39,27),PCOR(39,27),BTABAC(39)
     2,PCAR(39,27),ABSCAR(39),BTACAR(39),ABSSO4(39),ABSCOR(39),
     3 ABSPRM(39),GSO4(39),GCOR(39),GPRM(39),GCAR(39),GAER(39)
     4,GBAC(39),PBAC(39,27)
      COMMON/ MISC/ ABSNO2(39),SOLAR(39),RAD,FORPIN,OMZ(39),OMH(39)
     1,NTHETA,RFR,RFI
      COMMON/MIESCT/ROG,SIGMA,NLAMB,LAMB(20),JX,IT,TT(200),DUM(20),
     1PDUM(20,50),DUMA(20),DUMG(20)
      COMMON/DIFFI/FLUXUP(39),DIFIDN(39,21,41),DIFIUP(39,21,41)
      COMMON/DIFRAY/DIFRDN(9,21,41),DIFRUP(9,21,41)
      COMMON/PLM/PPLM(39,27)
      DIMENSION YMU(21),XAZI(41),XAZ(21),ERP(9),
     2SUMT(39),GI(39),SPECBI(39),SPB(9),SPP(9)
     3,DFIDN(9,21,41),DFIUP(9,21,41),DUMP(41),DS(2)
     4,COEF(57),W(57),GII(9),PBT(9),PPT(9)
      DATA YMU/1.0,0.95,0.9,0.85,0.8,0.75,0.7,0.65,0.6,0.55,0.5,
     20.45,0.40,0.35,0.30,0.25,0.20,0.15,0.10,0.05,0.0/
      DATA XAZI/0.,9.,18.,27.,36.,45.,54.,63.,72.,81.,90.,
     299.,108.,117.,126.,135.,144.,153.,162.,171.,180.,
     3189.,198.,207.,216.,225.,234.,243.,252.,261.,270.,
     4279.,288.,297.,306.,315.,324.,333.,342.,351.,360./
      PI=3.14159
      RAD=PI/180.
      UR=SIN(BETA*RAD)
C     WRITE(6,654)BETA,DF,IPF
C 654 FORMAT(/,3(2X,E13.4))
C
      IF(IPF.EQ.2)GO TO 172
      IEV=0
      DO 171 I=1,9
      IF(IPF.EQ.1)GO TO 304
      PBT(I)=0.1*PBAC(I,1)
      GO TO 305
  304 PPT(I)=0.1*PPLM(I,1)
  305 CONTINUE
      SPB(I)=0.
      SPP(I)=0.
      DO 171 J=1,21
      DO 171 K=1,41
      DFIDN(I,J,K)=1.0
      DFIUP(I,J,K)=1.0
  171 CONTINUE
      DO 310 I=1,7
C     WRITE(6,311)PBAC(1,I)
C 311 FORMAT(2X,E13.4)
  310 CONTINUE
      GO TO 302
  172 CONTINUE
  301 CONTINUE
      IF(IPF.EQ.2) GO TO 70
      DO 71 I=1,9
      DO 71 J=1,21
      DO 71 K=1,21
      DFIDN(I,J,K)=DIFIDN(I,J,K)
      DFIUP(I,J,K)=DIFIUP(I,J,K)
   71 CONTINUE
      GO TO 72
   70 DO 73 I=1,9
      DO 73 J=1,21
      DO 73 K=1,21
      DFIDN(I,J,K)=DIFRDN(I,J,K)
      DFIUP(I,J,K)=DIFRUP(I,J,K)
   73 CONTINUE
   72 CONTINUE
      DO 91 I=1,9
      DO 91 J=1,21
      DO 91 K=22,41
      DFIDN(I,J,K)=DFIDN(I,J,42-K)
      DFIUP(I,J,K)=DFIUP(I,J,42-K)
   91 CONTINUE
  302 CONTINUE
C
C     COMPUTE THE DIFFUSE RADIATION INTEGRAL
C
      DO 30 II=1,9
      I=5*(II-2)+4
      IF(II.EQ.1) I=1
      JJ=1
      SUMT(II)=0.
      DO 16 J=1,21
      U=YMU(J)
      SUM=0.
      KK=1
      DO 13 K=1,41
      D=XAZI(K)
      DI=(DF-D)*RAD
      IF(U.EQ.1.)GO TO 81
      IF(UR.EQ.1.)GO TO 81
      CTHET=U*UR+SQRT(1.-U**2)*SQRT(1.-UR**2)*COS(DI)
      GO TO 82
   81 CTHET=U*UR
   82 ACTHET=ABS(CTHET)
      IF(ACTHET.GE.1.)GO TO 83
      IF(ACTHET.EQ.0.)GO TO 183
      THET=ACOS(CTHET)/RAD
      GO TO 84
   83 THET=0.
      GO TO 84
  183 THET=90.
   84 CONTINUE
      IF(THET.LT.180.) GO TO 44
      THET=360.-THET
   44 DO 40 ITHETA=2,7
   40 IF(THET.LE.TT(ITHETA))GO TO 41
   41 Z=(THET-TT(ITHETA-1))/(TT(ITHETA)-TT(ITHETA-1))
      IF(IPF.EQ.1)GO TO 42
      IF(IPF.EQ.2)GO TO 45
      PTHETA=10.**(ALOG10(PBAC(I,ITHETA))*Z+ALOG10(PBAC(I,ITHETA-1))
     2*(1.-Z))
      IF(IEV.EQ.1)GO TO 140
      IF(PTHETA.LE.PBT(II))GO TO 141
      SPB(II)=SPB(II)+PTHETA*FLOAT(KK)*FLOAT(JJ)
  141 CONTINUE
      GO TO 143
  140 IF(PTHETA.LE.PBT(II))GO TO 143
      PTHETA=PTHETA*(1.0-ERP(II)/SPB(II))
  143 CONTINUE
      GO TO 43
   42 PTHETA=10.**(ALOG10(PPLM(I,ITHETA))*Z+ALOG10(PPLM(I,ITHETA-1))
     2*(1.-Z))
      IF(IEV.EQ.1)GO TO 144
      IF(PTHETA.LE.PPT(II))GO TO 145
      SPP(II)=SPP(II)+PTHETA*FLOAT(KK)*FLOAT(JJ)
  145 CONTINUE
      GO TO 147
  144 IF(PTHETA.LE.PPT(II))GO TO 147
      PTHETA=PTHETA*(1.-ERP(II)/SPP(II))
  147 CONTINUE
      GO TO 43
   45 PTHETA=0.75*(1.+COS(RAD*THET)**2)
   43 CONTINUE
C     IF(II.GT.1)GO TO 1001
C     PPD=PTHETA*DFIDN(II,J,K)
C     WRITE(6,1000)II,J,K,PTHETA,DFIDN(II,J,K),PPD
C1000 FORMAT(3(1X,I5),3(1X,E13.4))
C1001 CONTINUE
C     WRITE(6,68)J,K,SUM
      IF(KK.GT.1)GO TO 11
      SUM=DFIDN(II,J,K)*PTHETA + SUM
      KK=4
      GO TO 13
   11 IF(KK.GT.2)GO TO 12
      SUM=2.*DFIDN(II,J,K)*PTHETA + SUM
      KK=4
      GO TO 13
   12 SUM=4.*DFIDN(II,J,K)*PTHETA + SUM
      KK=2
      IF(K.EQ.40) KK=1
   13 CONTINUE
      SUM=SUM/3.*9.*RAD
C     WRITE(6,69)J,K,SUM,SUMT(II)
      IF(JJ.GT.1) GO TO 14
      SUMT(II)=SUM + SUMT(II)
      JJ=4
      GO TO 16
   14 IF(JJ.GT.2) GO TO 15
      SUMT(II)=2.*SUM + SUMT(II)
      JJ=4
      GO TO 16
   15 SUMT(II)=4.*SUM + SUMT(II)
      JJ=2
      IF(J.EQ.20) JJ=1
   16 CONTINUE
      JJ=1
      DO 26 J=1,21
      U=-YMU(J)
      SUM=0.
      KK=1
      DO 23 K=1,41
      D=XAZI(K)
      DI=(DF-D)*RAD
      IF(U.EQ.1.)GO TO 85
      IF(UR.EQ.1.)GO TO 85
      CTHET=U*UR+SQRT(1.-U**2)*SQRT(1.-UR**2)*COS(DI)
      GO TO 86
   85 CTHET=U*UR
   86 ACTHET=ABS(CTHET)
      IF(ACTHET.GE.1.)GO TO 87
      IF(ACTHET.EQ.0.)GO TO 187
      THET=ACOS(CTHET)/RAD
      GO TO 88
   87 THET=0.
      GO TO 88
  187 THET=90.
   88 CONTINUE
      IF(THET.LT.180.) GO TO 54
      THET=360.-THET
   54 DO 50 ITHETA=2,7
   50 IF(THET.LE.TT(ITHETA))GO TO 51
   51 Z=(THET-TT(ITHETA-1))/(TT(ITHETA)-TT(ITHETA-1))
      IF(IPF.EQ.1)GO TO 52
      IF(IPF.EQ.2)GO TO 55
      PTHETA=10.**(ALOG10(PBAC(I,ITHETA))*Z+ALOG10(PBAC(I,ITHETA-1))
     2*(1.-Z))
      IF(IEV.EQ.1)GO TO 240
      IF(PTHETA.LE.PBT(II))GO TO 241
      SPB(II)=SPB(II)+PTHETA*FLOAT(KK)*FLOAT(JJ)
  241 CONTINUE
      GO TO 243
  240 IF(PTHETA.LE.PBT(II))GO TO 243
      PTHETA=PTHETA*(1.0-ERP(II)/SPB(II))
  243 CONTINUE
      GO TO 53
   52 PTHETA=10.**(ALOG10(PPLM(I,ITHETA))*Z+ALOG10(PPLM(I,ITHETA-1))
     2*(1.-Z))
      IF(IEV.EQ.1)GO TO 244
      IF(PTHETA.LE.PPT(II))GO TO 245
      SPP(II)=SPP(II)+PTHETA*FLOAT(KK)*FLOAT(JJ)
  245 CONTINUE
      GO TO 247
  244 IF(PTHETA.LE.PPT(II))GO TO 247
      PTHETA=PTHETA*(1.-ERP(II)/SPP(II))
  247 CONTINUE
      GO TO 53
   55 PTHETA=0.75*(1.+COS(RAD*THET)**2)
   53 CONTINUE
C     IF(II.GT.1)GO TO 1002
C     PPD=PTHETA*DFIUP(II,J,K)
C     WRITE(6,1000)II,J,K,PTHETA,DFIUP(II,J,K),PPD
C1002 CONTINUE
C     WRITE(6,68)J,K,SUM
C  68 FORMAT(/,2X,I5,2X,I5,2X,E13.4)
      IF(KK.GT.1)GO TO 21
      SUM=DFIUP(II,J,K)*PTHETA + SUM
      KK=4
      GO TO 23
   21 IF(KK.GT.2)GO TO 22
```

SUBROUTINE INTEG(DF,BETA,IPF,GI)

```
           SUM=2.*DFIUP(II,J,K)*PTHETA + SUM
           KK=4
           GO TO 23
      22 SUM=4.*DFIUP(II,J,K)*PTHETA + SUM
           KK=2
           IF(K.EQ.40) KK=1
      23 CONTINUE
           SUM=SUM/3.*9.*RAD
 C        WRITE(6,69)J,K,SUM,SUMT(II)
 C    69 FORMAT(/,2X,I5,2X,I5,2X,E13.4,2X,E13.4)
           IF(JJ.GT.1) GO TO 24
           SUMT(II)=SUM + SUMT(II)
           JJ=4
           GO TO 26
      24 IF(JJ.GT.2) GO TO 25
           SUMT(II)=2.*SUM + SUMT(II)
           JJ=4
           GO TO 26
      25 SUMT(II)=4.*SUM + SUMT(II)
           JJ=2
           IF(J.EQ.2[illegible]) JJ=1
      26 CONTINUE
           SUMT(II)=SUMT(II)/3.*0.05
           GII(II) = OMZ(I)*SUMT(II)/(4.*PI)
           ERP(II)=(SUMT(II) - 4.0*PI)/(RAD*0.05)
 C        WRITE(6,65)II,SUMT(II),ERP(II),SPB(II),PBT(II)
 C    65 FORMAT(/,2X,I5,4(2X,E13.4))
      30 CONTINUE
           IF(IEV.EQ.1)GO TO 300
           IEV=1
           GO TO 301
 C
 C          INTERPOLATE FOR THE DIFFUSE FIELD INTEGRAL
 C          AT 39 WAVELENGTHS
 C
     300 CONTINUE
           DO 80 I=1,39
           J=IFIX((I+5)/5)
           Z=FLOAT((I+5)-5*J)*0.2
           GI(I)=Z*(GII(J+1)-GII(J))+GII(J)
 C        WRITE(6,66)I,GI(I)
 C    66 FORMAT(/,2X,I5,2X,E13.4)
      80 CONTINUE
           RETURN
           END
PROGRAM SIZE:    PROCEDURE - 003370     LINKAGE - 076134     STACK - 000070
0000 ERRORS [<INTEG >FTN-REV18.2]
```

```
      SUBROUTINE BACCLI(U,U0,DD,SPECBI,SPECBU)
C
C   CALCULATE SPECTRAL RADIANCE OF CLEAR SKY OF GIVEN BACKGROUND ATMOS-
C   PHERE WITH NO2 AND FINE AND COARSE AEROSOL.
C
      COMMON/RADPRP/BTASO4(39),BTACOR(39),BTAPRM(39),BTAAER(39),
     1PAER(39,27),PPRIM(39,27),PSO4(39,27),PCOR(39,27),BTABAC(39)
     2,PCAR(39,27),ABSCAR(39),BTACAR(39),ABSSO4(39),ABSCOR(39),
     3 ABSPRM(39),GSO4(39),GCOR(39),GPRM(39),GCAR(39),GAER(39)
     4,GBAC(39),PBAC(39,27)
      COMMON/ OPTDEP / TATOIZ(39),TATHIZ(39),TATOHZ(39),X1(39),
     1X2(39),TAUTDI(39),TAUTOD(39),XHDI(39),XHOD(39)
      COMMON/ MISC/ ABSNO2(39),SOLAR(39),RAD,FORPIN,OMZ(39),OMH(39)
     1,NTHETA,RFR,RFI
      COMMON / ISAACS / IRE
      COMMON/DIFFI/FLUXUP(39),DIFIDN(39,21,41),DIFIUP(39,21,41)
      DIMENSION SPECBI(39),SPECBU(39)
      REAL I1,I2,K
      DATA PI/3.14159265358/
C
      DTR(X)=PI/180.*X
      RTD(X)=180./PI*X
C     IF(BETA.LT.1.5) BETA=1.5
C     D=(COS(RAD*THETA)-U0*U)/(SQRT(1.-U**2)*SQRT(1.-U0**2))
C     AD=ABS(D)
C     IF(AD.GT.1)GO TO 23
C     D=ACOS(D)/RAD
      A1=0.3
      IF(U.LT.0.0262) U=0.0262
C     WRITE(6,10)U,U0,DD
C  10 FORMAT(/,3(2X,E13.4))
      DO 50 II=1,9
      I=5*(II-2)+4
      IF(II.EQ.1) I=1
      T0=TATOIZ(I)
      W0=OMZ(I)
      F=SOLAR(I)/PI
      G=GBAC(I)
      IF(IRE.GT.1) GO TO 543
C     WRITE(6,250)T0,W0,F,G
C 250 FORMAT(/,4(2X,E13.4))
  543 CONTINUE
      CALL HGSCT(U,U0,DD,G,W0,B0,B1,B2,P1,P2)
C
C     DEFINE CONSTANTS
C
      G1=2.*(1.-W0*(1.-B1))
      G2=2.*W0*B1
C     WRITE(6,300) G1,G2
C300  FORMAT(2(1X,E13.4),/)
      K=G1**2-G2**2
      IF(K.LE.0.)GO TO 1
      K=SQRT(G1*G1-G2*G2)
      GO TO 2
    1 K=0.
    2 C=PI*F*W0*(B0/U0-G2*(1.-B0)-G1*B0)*U0**2/(1.-K**2*U0**2)
      E1=(C*(G1+1./U0)-PI*F*W0*B0)*(1./(G1-K)-A1/G2)
      E2=-C+PI*F*U0*A1+A1/G2*(C*(G1+1./U0)-PI*F*W0*B0)
      E3=(G1+K)*(-1./(G1-K)+A1/G2)
      E4=1.-A1/G2*(G1+K)
      B=(E1*EXP(K*T0)+E2*EXP(-T0/U0))/(E3*EXP(K*T0)+E4*EXP(-K*T0))
      A=(B*(G1+K)+(C*(G1+1./U0)-PI*F*W0*B0))/(K-G1)
C
C     COMPUTE INTENSITIES
C
      U1=A*(W0/PI)*(1.-B2+B2/G2*(G1-K))
      U2=B*(W0/PI)*(1.-B2+B2/G2*(G1+K))
      U3=C*(W0/PI)*(1.-B2)+W0*B2/(PI*G2)*C*(G1+1./U0-PI*F*W0*B0)+F/4.*PI
C
      F5=A*EXP(K*T0)+B*EXP(-K*T0)+C*EXP(-T0/U0)
C
      D2=F5/A-U1*EXP(K*T0)/(1.-U*K)
      D3=-U2*EXP(-K/T0)/(1.+U*K)-U3*EXP(-T0/U)/(1.+U/U0)
      D1=EXP(-T0/U)*(D2+D3)
C
C     UPWARD INTENSITY
C
      T=0.
      I1=D1*EXP(T/U)+U1*EXP(K*T)/(1.-U*K)+U2*EXP(-K*T)/(1.+U*K)
     1 +U3*EXP(-T/U0)/(1.+U/U0)
      FLUXUP(II) = A*EXP(K*T0) + B*EXP(-K*T0) + C*EXP(-T0/U0)
      SPECBU(II)=FLUXUP(II)/PI
C
C     DOWNWARD INTENSITY
C
      T=T0
      W1=W0/PI*A*(1.-U*K)/(1.+U*K)*(B2+(1.-B2)*(G1-K)/G2)
      W2=W0/PI*B*(1.+U*K)/(1.-U*K)*(B2+(1.-B2)*(G1+K)/G2)
      Y=C*(G1+1./U0)-PI*F*W0*B0
      W3=(U0+U)/(U0-U)*(W0/PI*B2*C+W0/PI*(1.-B2)*Y/G2+F/4.*P2)
      E1=-(W1/(1.-U*K)+W2/(1.+U*K)+W3/(1.+U/U0))
      SPECBI(II)=E1*EXP(-T/U)+W1*EXP(K*T)/(1.-U*K)+W2*EXP(-K*T)/(1.+U*K)
     1 +W3*EXP(-T/U0)/(1.+U/U0)
C     IF(SPECBI(II).GT.0.) GO TO 50
C     SPECBI(II) = 10.
C     WRITE(6,400) SPECBI(II)
C 400 FORMAT(/,2X,E13.4,/)
   50 CONTINUE
      GO TO 24
C  23 DO 25 I=1,9
C     SPECBI(I)=10.0
C     WRITE(6,400) SPECBI(I)
C 25  CONTINUE
 24   RETURN
      END
PROGRAM SIZE:   PROCEDURE - 002006    LINKAGE - 000152    STACK - 000112
0000 ERRORS [<BACCLI>FTN-REV18.2]
```

SUBROUTINE HGSCT(U,U0,D1,G,W0,B0,B1,B2,P1,P2)

```
      SUBROUTINE HGSCT(U,U0,D1,G,W0,B0,B1,B2,P1,P2)
      COMMON / ISAACS / IRE
      DIMENSION A9(10,5),U8(9),U9(2),B7(2)
      DATA A9/.5,.5,.5,.5,.5,.5,.5,.5,.5,.5,
     2.0,.13979292889,-.12019000482,-.46017123188,-.406828796532,
     3-.3001541656,-.553474414782,-.626794663911,-.84678101,
     4-.406823676662,.0,-1.5989873995,-.2724219928,1.18747390274,
     5.49409050834,-.35928947292,.37397957743,.18057740986,
     6.50718036245,.01406832224,.0,3.5184116963,.6385960123,
     7-2.081230849,-1.0144699491,.1589475781,-.74761782865,
     8-.37416958202,-.374040109,.1055607702,.0,-2.5592172257,
     9-.7459840146,.85392041407,.4272082373,.00049606046,
     1.42711266606,.32038683614,.2136746594,-.2128054157/
      DATA U8/0.0,.1,.2,.3,.4,.5,.6,.8,1.0/
      DATA PI/3.14159265358/
C
      DTR(X)=PI/180.*X
      RTD(X)=180./PI*X
C
C    READ A9
C
C     WRITE(6,66) IRE
C 66  FORMAT(I5)
C     CLOSE(UNIT=5)
C
C     BACKSCATTERING INTERPOLATION
C
      U9(1)=U
      U9(2)=U0
           IF(W0.EQ.1.0) W0 = 0.99999
      DO 50 IR=1,2
      IF(U9(IR).LT. .1) GO TO 10
      IF(U9(IR).LT. .2) GO TO 12
      IF(U9(IR).LT. .3) GO TO 14
      IF(U9(IR).LT. .4) GO TO 16
      IF(U9(IR).LT. .5) GO TO 18
      IF(U9(IR).LT. .6) GO TO 20
      IF(U9(IR).LT. .8) GO TO 22
      IF(U9(IR).LE.1.0) GO TO 24
   10 IQ=1
      GO TO 25
   12 IQ=2
      GO TO 25
   14 IQ=3
      GO TO 25
   16 IQ=4
      GO TO 25
   18 IQ=5
      GO TO 25
   20 IQ=6
      GO TO 25
   22 IQ=7
      GO TO 25
   24 IQ=8
C
   25 Y5=0.0
      Y6=0.0
      Y7=0.0
```

```
            IQP1=IQ+1
C
            DO 30 J=1,5
            JM1=J-1
            Y9=A9(IQ,J)*G**JM1
            Y8=A9(IQP1,J)*G*JM1
            Y3=A9(10,J)*G**JM1
            Y7=Y7+Y9
            Y6=Y6+Y8
            Y5=Y5+Y3
       30   CONTINUE
            B7(IR)=Y7+(Y6-Y7)*(U9(IR)-U8(IQ))/(U8(IQP1)-U8(IQ))
       50   CONTINUE
C
            B1=Y5
            B2=B7(1)
            B0=B7(2)
C
            D=DTR(D1)
            C1=-U*U0+SQRT(1.-U*U)*SQRT(1.-U0*U0)*COS(D)
            C2=U*U0+SQRT(1.-U*U)*SQRT(1.-U0*U0)*COS(D)
            S=ACOS(-C2)
            S1=RTD(S)
            P1=W0*(1.-G*G)/(1.+G*G-2.*G*C1)**1.5
            P2=W0*(1.-G*G)/(1.+G*G-2.*G*C2)**1.5
C           WRITE(6,170)
C170        FORMAT(//,10X,'H-G PHASE FUNCTION',//)
C           WRITE(6,175) S1
C175        FORMAT(2X,'SCATTERING ANGLE',1X,F7.3,1X,'DEG',//)
C           WRITE(6,180) P1,P2
C180        FORMAT(2X,'PUP',F12.6,' PDOWN',F12.6,//)
            IRE=IRE+1
            RETURN
            END
PROGRAM SIZE:   PROCEDURE - 000760    LINKAGE - 000274    STACK - 000122
0000 ERRORS [<BGSCT >FTN-REV18.2]
```

SUBROUTINE BACOBJ(ZENITH,BETA,THETA,ITHETA,RO,SPECO,XLUMIN)

```
      SUBROUTINE BACOBJ(ZENITH,BETA,THETA,ITHETA,RO,SPECO,XLUMIN)
C
C   CALCULATE SPECTRAL RADIANCE OF VIEWING BACKGROUNDS OF SPECIFIED
C   REFLECTANCE AS VIEWED THROUGH BACKGROUND ATMOSPHERE.
C
      COMMON/RADPRP/BTASO4(39),BTACOR(39),BTAPRM(39),BTAAER(39),
     1PAER(39,27),PPRIM(39,27),PSO4(39,27),PCOR(39,27),BTABAC(39)
     2,PCAR(39,27),ABSCAR(39),BTACAR(39),ABSSO4(39),ABSCOR(39),
     3 ABSPRM(39),GSO4(39),GCOR(39),GPRM(39),GCAR(39),GAER(39)
     4,GBAC(39),PBAC(39,27)
      COMMON/ OPTDEP / TATOIZ(39),TATHIZ(39),TATOHZ(39),X1(39),
     1X2(39),TAUTDI(39),TAUTOD(39),XHDI(39),XHOD(39)
      COMMON/ MISC/ ABSNO2(39),SOLAR(39),RAD,FORPIN,OMZ(39),OMH(39)
     1,NTHETA,RFR,RFI
      DIMENSION SPECO(39),GI(39)
      TWOPI = .5/FORPIN
      RHO = .3
      RHOPI = 0.5*RHO*TWOPI
      XMU0 = COS(RAD*ZENITH)
      XMU = SIN(RAD*BETA)
      PRAY = 0.75*(1.+COS(RAD*THETA)**2)
      IPF = 0
      XMUR=SIN(BETA*RAD)
      XMU0=COS(ZENITH*RAD)
      COSTTA=COS(THETA*RAD)
      IF(BETA.EQ.90.)GO TO 30
      CDR=(COSTTA-XMUR*XMU0)/(SQRT(1.-XMU0**2)*
     2SQRT(1.-XMUR**2))
      GO TO 31
   30 IF(THETA.NE.ZENITH)GO TO 60
      DF=0.
      GO TO 32
   31 CONTINUE
      ACDR=ABS(CDR)
      IF(ACDR.GT.1.) GO TO 60
      DF=ACOS(CDR)/RAD
   32 CONTINUE
C     WRITE(6,64)BETA,DF,THETA
      CALL INTEG(DF,BETA,IPF,GI)
      DO 50 I = 1,39
      FD0 = SOLAR(I)*EXP(-TATOIZ(I)/XMU0)
      FDH = SOLAR(I)*EXP(-TATHIZ(I)/XMU0)
      FDAV = (FD0 + FDH)*0.5
      PTOTOD = XHOD(I)*PRAY + (1.-XHOD(I))*PAER(I,ITHETA)
      PTOTOD = PTOTOD*OMH(I)
      TRO = EXP(-BTABAC(I)*RO)
      SPECO(I) = XLUMIN*FDH*TRO + FORPIN*PTOTOD*(1.-TRO)*FDAV
      SPECO(I) = SPECO(I) + GI(I)
   50 CONTINUE
      GO TO 63
   60 DO 61 I=1,39
      SPECO(I)=1.
   61 CONTINUE
C     WRITE(6,64)BETA,CDR,THETA
C  64 FORMAT(/,3(X,E13.4))
C     WRITE(6,62)
C 62  FORMAT(/,' THIS THETA ANGLE IS NOT POSSIBLE ',/)
   63 RETURN
```

```
          END
PROGRAM SIZE:   PROCEDURE - 000564    LINKAGE - 000242    STACK - 000100
0000 ERRORS [<BACOBJ>FTN-REV18.2]
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```
      SUBROUTINE PLMCLN(ZENITH,BETA,THETA,ITHETA,PLUMEP,PLUMES,
     1PLUMEN,PLUMEC,SPECB,SPECP,RP,THICK)
C
C  CALCULATE SPECTRAL RADIANCES OF THE CLEAR SKY VIEWED WITH LINES
C  OF SIGHT THROUGH THE PLUME AND BACKGROUND ATMOSPHERE.
C
      COMMON/RADPRP/BTASO4(39),BTACOR(39),BTAPRM(39),BTAAER(39),
     1PAER(39,27),PPRIM(39,27),PSO4(39,27),PCOR(39,27),BTABAC(39)
     2,PCAR(39,27),ABSCAR(39),BTACAR(39),ABSSO4(39),ABSCOR(39),
     3 ABSPRM(39),GSO4(39),GCOR(39),GPRM(39),GCAR(39),GAER(39)
     4,GBAC(39),PBAC(39,27)
      COMMON/ OPTDEP / TATOIZ(39),TATHIZ(39),TATOHZ(39),X1(39),
     1X2(39),TAUTDI(39),TAUTOD(39),XHDI(39),XHOD(39)
      COMMON/ MISC/ ABSNO2(39),SOLAR(39),RAD,FORPIN,OMZ(39),OMH(39)
     1,NTHETA,RFR,RFI
      COMMON/PLM/PPLM(39,27)
      DIMENSION SPECB(39),SPECP(39),GI(39)
      DIMENSION OMEGIP(39),TPI2(39),DIFI(39),SPECPI(39)
      DIMENSION FDAVI(39),TPI1(39),PTOTI(39),PTOPI(39)
      DIMENSION ATFAC(39),DGI(39)
      TWOPI = 0.5/FORPIN
      RHO = .3
      RHOPI = 0.5*RHO*TWOPI
      XMU0 = COS(RAD*ZENITH)
      XMU = SIN(RAD*BETA)
      PRAY = 0.75*(1.+COS(RAD*THETA)**2)
      IPF = 0
      XMUR=SIN(BETA*RAD)
      XMU0=COS(ZENITH*RAD)
      COSTTA=COS(THETA*RAD)
      IF(BETA.EQ.90)GO TO 40
      CDR=(COSTTA-XMUR*XMU0)/(SQRT(1.-XMU0**2)*
     2SQRT(1.-XMUR**2))
      GO TO 41
   40 IF(THETA.NE.ZENITH)GO TO 60
      DF=0.
      GO TO 42
   41 CONTINUE
      ACDR=ABS(CDR)
      IF(ACDR.GT.1.) GO TO 60
      DF=ACOS(CDR)/RAD
   42 CONTINUE
      CALL INTEG(DF,BETA,IPF,GI)
      IF(BETA.EQ.0.) GO TO 100
      DO 50 I = 1,39
      FDO = SOLAR(I)*EXP(-TATOIZ(I)/XMU0)
      FDH = SOLAR(I)*EXP(-TATHIZ(I)/XMU0)
      FDAV = (FDO + FDH)*0.5
      PTOTDI = X1(I)*PRAY + (1.-X1(I))*PAER(I,ITHETA)
      PTOTOD = X2(I)*PRAY + (1. - X2(I))*PAER(I,ITHETA)
      PTOTOD = PTOTOD*OMZ(I)
      SKY = FORPIN*PTOTDI*(1.-EXP(-TATHIZ(I)/XMU))*SOLAR(I)
      SURF = SKY*EXP(-TATOHZ(I)/XMU) + FORPIN*PTOTOD*(1.-EXP(-TATOHZ(I
     1)/XMU))*FDAV
      SPECB(I) = SURF + GI(I)*(1.-EXP(-TATOIZ(I)/XMUR))
C     WRITE(6,1234)I,SURF,GI(I)
 1234 FORMAT(1H ,5X,'I = ',I2,', SURF  = ',E9.3,', GI(I) = ',E9.3)
   50 CONTINUE
```

```
      GO TO 200
  100 CONTINUE
C*****
C***  DO THE HORIZONTAL CASE
C*****
      DO 75 I = 1,39
      FD0 = SOLAR(I)*EXP(-TATOIZ(I)/XMU0)
      FDH = SOLAR(I)*EXP(-TATHIZ(I)/XMU0)
      FDAV = (FD0 + FDH)*0.5
      PTOTDI = PRAY*XHDI(I) + (1.-XHDI(I))*PAER(I,ITHETA)
      PTOTOD = XHOD(I)*PRAY + (1.-XHOD(I))*PAER(I,ITHETA)
       PTOTOD = PTOTOD*OMH(I)
      SKYH = FORPIN*PTOTDI*(1.-EXP(-TAUTDI(I)))*SOLAR(I)
C
C      *************** DIAGNOSTIC PRINT OUT *************
C
C     WRITE(6,1003)I,PTOTDI,TAUTDI(I),SOLAR(I)
 1003 FORMAT(1H ,'I = ',I2,', PTOTDI = ',E9.3,', TAUTDI(I) = ',E9.3,
     1 ', SOLAR(I) = ',E9.3)
C     WRITE(6,1004)PAER(I,ITHETA),XHDI(I),XHOD(I)
 1004 FORMAT(1H ,'PAER(I,ITHETA) = ',E9.3,', XHDI(I) = ',E9.3,
     1 ', XHOD(I) =',E9.3)
C
C     ************************************************
C
      SURFH = SKYH*EXP(-TAUTOD(I)) + FORPIN*PTOTOD*(1.-EXP(-TAUTOD(I)))
     1*FDAV
C
C     *********** DIAGNOSTIC PRINT OUT ***************
C
C     WRITE(6,1002)I,SURFH,SKYH,TAUTOD(I),PTOTOD,FDAV
 1002 FORMAT(1H ,5X,'I = ',I2,', SURFH = ',E9.3,', SKYH = ',E9.3,
     1 ', TAUTOD(I) = ',E9.3,', PTOTOD = ',E9.3,', FDAV = ',E9.3)
C
C     *************************************************
C
      SPECB(I) = SURFH + GI(I)*(1.-EXP(-TAUTOD(I)-TAUTDI(I)))
C
C  *************  DIAGNOSTIC PRINT OUT
C
C     WRITE(6,1000)I,SURFH,GI(I)
 1000 FORMAT(1H ,5X,'I = ',I2,', SURFH = ',E9.3,', GI(I) = ',E9.3)
C
C    *******************************************************
C
   75 CONTINUE
  200 CONTINUE
      DO 250 I = 1,39
C*****
C***  COMPUTE THE PLUME TRANSMISSION
C*****
      FD0 = SOLAR(I)*EXP(-TATOIZ(I)/XMU0)
      FDH = SOLAR(I)*EXP(-TATHIZ(I)/XMU0)
      FDAV = (FD0+FDH)*.5
      FDAVI(I) = FDAV
      TAUP1 = BTABAC(I)*RP
      TAPSO4 = BTASO4(I)*PLUMES
      TAPNO2 = ABSNO2(I)*PLUMEN
      TAPRIM = BTAPRM(I)*PLUMEP + PLUMEC*BTACAR(I)
      TAUP2   = TAPSO4 + TAPNO2 + TAPRIM
      IF(I.EQ.19) THICK=TAUP2
      TAPTOT = TAUP1 + TAUP2
      XD2 = TAPSO4/(TAPSO4 + TAPRIM)
      OMEGAP = 1. - (TAPNO2+PLUMEC*ABSCAR(I)+PLUMES*ABSSO4(I)
     1 +PLUMEP*ABSPRM(I))/TAUP2
      OMEGIP(I) = OMEGAP
      XD3 = PLUMEC*BTACAR(I)/(PLUMEC*BTACAR(I)+PLUMEP*BTAPRM(I))
      PTOTPL = XD2*PSO4(I,ITHETA) + (1.-XD2)*PPRIM(I,ITHETA)*(1.-XD3)
     1 + (1.-XD2)*XD3*PCAR(I,ITHETA)
      PTOPI(I) = PTOTPL
      TP1 = EXP(-TAUP1)
      TPI1(I)=TP1
      TP2 = EXP(-TAUP2)
      TPI2(I) = TP2
      TPTOT = EXP(-TAPTOT)
      PTOTOD = XHOD(I)*PRAY + (1.-XHOD(I))*PAER(I,ITHETA)
      PTOTOD = PTOTOD*OMH(I)
      PTOTI(I) = PTOTOD
      DIFI(I) = GI(I)*(1.-TP1)
      SPECBI=(SPECB(I)-FORPIN*(1.-TP1)*PTOTOD*FDAV-DIFI(I))/TP1
      PLI=SPECBI*TP2+OMEGAP*FORPIN*PTOTPL*FDAV*(1.-TP2)
      SPECPI(I)=PLI*TP1+FORPIN*PTOTOD*(1.-TP1)*FDAV+DIFI(I)
      DO 252 J=1,7
      PPLM(I,J) = XD2*PSO4(I,J) + (1.-XD2)*PPRIM(I,J)*(1.-XD3)
     1 + (1.-XD2)*XD3*PCAR(I,J)
C     WRITE(6,1235)PPLM(I,J)
 1235 FORMAT(2X,' PPLM = ',E13.4)
  252 CONTINUE
C
C   ***************** DIAGNOSTIC PRINT OUT *********************
C
C     WRITE(6,1001)I,SPECP(I),GI(I)
1001  FORMAT(1H ,5X,'I = ',I2,', SPECP(I) = ',E9.3,',  GI(I) = ',E9.3)
C
C      ************************************************
C
  250 CONTINUE
      IPF = 1
      XMUR=SIN(BETA*RAD)
      XMU0=COS(ZENITH*RAD)
      COSTTA=COS(THETA*RAD)
      IF(BETA.EQ.90)GO TO 30
      CDR=(COSTTA-XMUR*XMU0)/(SQRT(1.-XMU0**2)*
     2SQRT(1.-XMUR**2))
      GO TO 31
   30 IF(THETA.NE.ZENITH)GO TO 60
      DF=0.
      GO TO 32
   31 CONTINUE
      ACDR=ABS(CDR)
      IF(ACDR.GT.1.) GO TO 60
      DF=ACOS(CDR)/RAD
   32 CONTINUE
      CALL INTEG(DF,BETA,IPF,GI)
      DO 254 I=1,39
      SPECP(I) = SPECPI(I) + GI(I)*(1.-TPI2(I))*OMEGIP(I)*TPI1(I)
```

```
C     DGI(I) = SPECP(I)-SPECPI(I)
C     WRITE(6,1001)I,SPECP(I),GI(I)
  254 CONTINUE
C     WRITE (6,94)(DGI(I),I=1,39)
C     WRITE (6,94)(SPECPI(I),I=1,39)
C  94 FORMAT(//5(7(1X,E13.4)/),4(1X,E13.4))
      GO TO 63
   60 DO 61 I=1,39
      SPECP(I)=1.
      SPECB(I)=1.
   61 CONTINUE
C     WRITE(6,64)BETA,DP,THETA
C  64 FORMAT(/,3(X,E13.4))
      WRITE(6,62)
   62 FORMAT(/,' THIS THETA ANGLE IS IMPOSSIBLE ',/)
   63 RETURN
      END
PROGRAM SIZE:   PROCEDURE - 002742    LINKAGE - 002000    STACK - 000116
0000 ERRORS [<PLMCLN>FTN-REV18.2]
```

SUBROUTINE PLMOBJ(ZENITH,BETA,THETA,ITHETA,PLUMEP,

```
      SUBROUTINE PLMOBJ(ZENITH,BETA,THETA,ITHETA,PLUMEP,
     1PLUMES,PLUMEN,PLUMEC,XLUMIN,RO,RP,SPECO,SPECP)
C
C     CALCULATE SPECTRAL RADIANCE OF A VIEWED OBJECT OF GIVEN REFLECTANCE
C     FOR LINES OF SIGHT THROUGH PLUME AND BACKGROUND ATMOSPHERE.
C
      COMMON/RADPRP/BTASO4(39),BTACOR(39),BTAPRM(39),BTAAER(39),
     1PAER(39,27),PPRIM(39,27),PSO4(39,27),PCOR(39,27),BTABAC(39)
     2,PCAR(39,27),ABSCAR(39),BTACAR(39),ABSSO4(39),ABSCOR(39),
     3 ABSPRM(39),GSO4(39),GCOR(39),GPRM(39),GCAR(39),GAER(39)
     4,GBAC(39),PBAC(39,27)
      COMMON/ OPTDEP / TATOIZ(39),TATHIZ(39),TATOHZ(39),X1(39),
     1X2(39),TAUTDI(39),TAUTOD(39),XHDI(39),XHOD(39)
      COMMON/ MISC/ ABSNO2(39),SOLAR(39),RAD,FORPIN,OMZ(39),OMH(39)
     1,NTHETA,RFR,RFI
      COMMON/PLM/PPLM(39,27)
      DIMENSION SPECP(39),SPECO(39),GI(39)
      DIMENSION OMEGIP(39),TPI2(39),DIFI(39),SPECPI(39)
      DIMENSION FDAVI(39),TPI1(39),PTOTI(39),PTOPI(39)
      TWOPI = .5/FORPIN
      RHO = .3
      RHOPI = 0.5*RHO*TWOPI
      XMU0 = COS(RAD*ZENITH)
      XMU = SIN(RAD*BETA)
      PRAY = 0.75*(1.+COS(RAD*THETA)**2)
      IPF = 0
      XMUR=SIN(BETA*RAD)
      XMU0=COS(ZENITH*RAD)
      COSTTA=COS(THETA*RAD)
      IF(BETA.EQ.90)GO TO 40
      CDR=(COSTTA-XMUR*XMU0)/(SQRT(1.-XMU0**2)*
     2SQRT(1.-XMUR**2))
      GO TO 41
   40 IF(THETA.NE.ZENITH)GO TO 60
      DF=0.
      GO TO 42
   41 CONTINUE
      ACDR=ABS(CDR)
      IF(ACDR.GT.1.) GO TO 60
      DF=ACOS(CDR)/RAD
   42 CONTINUE
      CALL INTEG(DF,BETA,IPF,GI)
      DO 50 I = 1,39
      FD0 = SOLAR(I)*EXP(-TATOIZ(I)/XMU0)
      FDH = SOLAR(I)*EXP(-TATHIZ(I)/XMU0)
      FDAV = (FD0 + FDH)*0.5
      PTOTOD = XHOD(I)*PRAY + (1.-XHOD(I))*PAER(I,ITHETA)
      PTOTOD = PTOTOD*OMH(I)
      TRO = EXP(-BTABAC(I)*RO)
      SPECO(I) = XLUMIN*FDAV*TRO + FORPIN*PTOTOD*(1.-TRO)*FDAV
      SPECO(I) = SPECO(I) + GI(I)*(1.-TRO)
C*****
C***  COMPUTE THE PLUME TRANSMISSION
C*****
      TAUP1 = BTABAC(I)*RP
      TAPSO4 = BTASO4(I)*PLUMES
      TAPNO2 = ABSNO2(I)*PLUMEN
      TAPRIM = BTAPRM(I)*PLUMEP
      TAPRIM = TAPRIM + (BTACAR(I) + ABSCAR(I)) * PLUMEC
      TAUP2   = TAPSO4 + TAPNO2 + TAPRIM
      TAUP3 = BTABAC(I)*(RO-RP)
      TAPTOT = TAUP1 + TAUP2
      XD2 = TAPSO4/(TAPSO4 + TAPRIM)
      XD3 = PLUMEC*BTACAR(I)/(PLUMEC*BTACAR(I)+PLUMEP*BTAPRM(I))
      OMEGAP = 1. -(TAPNO2+PLUMEC*ABSCAR(I)+PLUMES*ABSSO4(I)
     1 +PLUMEP*ABSPRM(I))/TAUP2
      OMEGIP(I) = OMEGAP
      PTOTPL = XD2*PSO4(I,ITHETA) + (1.-XD2)*PPRIM(I,ITHETA)
     1 *(1.-XD3)+(1.-XD2)*XD3*PCAR(I,ITHETA)
      PTOPI(I) = PTOTPL
      TP1 = EXP(-TAUP1)
      TPI1(I)=TP1
      TP2 = EXP(-TAUP2)
      TPI2(I) = TP2
      TPTOT = EXP(-TAPTOT)
      TP3 = EXP(-TAUP3)
      PTOTOD = XHOD(I)*PRAY + (1.-XHOD(I))*PAER(I,ITHETA)
      PTOTOD = PTOTOD*OMH(I)
      PTOTI(I) = PTOTOD
      PL2 = XLUMIN*FDAV*TP3 + FORPIN*PTOTOD*FDAV*(1.-TP3)
      PL1 =       PL2*TP2 + OMEGAP*FORPIN*PTOTPL*FDAV*(1.-TP2)
      SPECP(I) = PL1*TP1 + FORPIN*PTOTOD*(1.-TP1)*FDAV
      DO 252 J=1,7
      PPLM(I,J) = XD2*PSO4(I,J) + (1.-XD2)*PPRIM(I,J)*(1.-XD3)
     1 + (1.-XD2)*XD3*PCAR(I,J)
C     WRITE(6,1235)PPLM(I,J)
 1235 FORMAT(2X,' PPLM = ',E13.4)
  252 CONTINUE
   50 CONTINUE
      IPF = 1
      XMUR=SIN(BETA*RAD)
      XMU0=COS(ZENITH*RAD)
      COSTTA=COS(THETA*RAD)
      IF(BETA.EQ.90)GO TO 30
      CDR=(COSTTA-XMUR*XMU0)/(SQRT(1.-XMU0**2)*
     2SQRT(1.-XMUR**2))
      GO TO 31
   30 IF(THETA.NE.ZENITH)GO TO 60
      DF=0.
      GO TO 32
   31 CONTINUE
      ACDR=ABS(CDR)
      IF(ACDR.GT.1.) GO TO 60
      DF=ACOS(CDR)/RAD
   32 CONTINUE
      CALL INTEG(DF,BETA,IPF,GI)
      DO 254 I=1,39
      SPECP(I) = SPECP(I) + GI(I)*(1.-TPI2(I))*OMEGIP(I)*TPI1(I)
C     WRITE(6,1001)I,SPECP(I),GI(I)
  254 CONTINUE
      GO TO 63
   60 DO 61 I=1,39
      SPECP(I)=1.
      SPECO(I)=1.
   61 CONTINUE
C     WRITE(6,64)BETA,DF,THETA
```

```
C  64 FORMAT(/,3(X,E13.4))
         WRITE(6,62)
   62 FORMAT(/,' THIS THETA ANGLE IS IMPOSSIBLE ',/)
   63 RETURN
         END
PROGRAM SIZE:   PROCEDURE - 001710    LINKAGE - 001522    STACK - 000122
0000 ERRORS [<PLMOBJ>FTN-REV18.2]
```

SUBROUTINE BSIZE

```
      SUBROUTINE BSIZE
C
C     CALCULATE OPTICAL PROPERTIES OF A GIVEN LOG-NORMAL AEROSOL SIZE
C     DISTRIBUTION BASED ON MIE SCATTERING THEORY
C
      COMMON/MIESCT/RVM,SIGMA,NLAMB,LAMB(20),JX,IT,TT(200),DUM(20),
     1PDUM(20,50),DUMA(20),DUMG(20)
      COMMON / RAIN / ITEST,IASD
      COMMON/ MISC/ ABSNO2(39),SOLAR(39),RAD,FORPIN,OMZ(39),OMH(39)
     1,NTHETA,RFR,RFI
      REAL LAMB
      REAL RFR,RFI,QEXT,QSCAT,QRPRD,ELTRMX(4,27,2),
     1 PIE(3,27),TAU(3,27),CSTHT(27),SI2THT(27)
      DIMENSION TT1(27)
      COMPLEX ACAP(7000)
      DIMENSION S1(27),S2(27),PHASE(27)
      DIMENSION XNT(200),ST(200),VT(200),R(200),DR(200)
C
      DIMENSION AL(31),ALALFA(154),ALPHA(154),QE(154),
     2STMTX(154,27)
     1,QS(154),QG(154),STMT(154,27)
      DIMENSION DOM(20,30),DOMA(20,30),DOMG(20,30),PDOM(9,22,8)
     2,RTMTS(200),STMTS(200)
C     **************** DIAGNOSTIC PRINT OUT ************
C
C     WRITE(6,1005)RVM,SIGMA,NLAMB,JX,IT
C     WRITE(6,1010)NTHETA,RFR,RFI
 1005 FORMAT(1H ,5X,'RVM = ',F6.3,1X,'SIGMA = ',F6.3,1X,'NLAMB = ',
     1 I3,1X,'JX = ',I3,1X,'IT = ',I3)
 1010 FORMAT(1H ,5X,'NTHETA = ',I3,1X,'RFR = ',F6.3,1X,'RFI = ',F6.3)
C
C *********** DIAGNOSTIC PRINT OUT *********************
C
      NT=NTHETA
      JX=NTHETA
      IT=27
      LL=7000
      DO 570 J=1,NTHETA
      IF(TT(J).LE.90.) GO TO 560
      TT1(J)=180.-TT(J)
      GO TO 570
  560 CONTINUE
      TT1(J)=TT(J)
  570 CONTINUE
      IF(ITEST.LT.1) GO TO 82
      IF(RFR.EQ.RFRT) GO TO 81
   82 DO 10 I=1,112
      ALPHA(I)=EXP(-4.8+0.1*I)
      ALP=ALPHA(I)
      ALALFA(I)=ALOG(ALPHA(I))
      CALL DAMIE(ALP,RFR,RFI,TT1,JX,QEXT,QSCAT,QRPRD,ELTRMX,PIE,TAU,
     2CSTHT,SI2THT,ACAP,IT,LL)
      QE(I)=QEXT
      QS(I)=QSCAT
      QG(I)=QRPRD
      DO 9 J=1,NTHETA
      IF(TT(J).NE.TT1(J)) GO TO 91
      STMTX(I,J)=0.5*(ELTRMX(1,J,1)+ELTRMX(2,J,1))
```

SUBROUTINE BSIZE

```
      GO TO 9
   91 CONTINUE
      JJ=J
      STMIX(I,JJ)=0.5*(ELTRMX(1,J,2)+ELTRMX(2,J,2))
    9 CONTINUE
   10 CONTINUE
   81 PI = 3.14159267
      IF(IASD.GT.0) GO TO 1
C
C INTEGRATION FOR A LOGNORMAL
C AEROSOL SIZE DISTRIBUTION
C
      TWOPI = 2.*3.14159267
       FTPIN = 3./(4.*PI)
      PIN = .75
   50 NPOINT = 15
      K = NPOINT
      ITWKP1 = 2*K + 1
      KP1 = K + 1
      KP2 = K + 2
      ALSIGM = ALOG(SIGMA)
      ALSGM2 = ALSIGM**2
      SIGM2 = ALSGM2
      SQRT2 = SQRT(2.)
      RSM = EXP(ALOG(RVM)-ALSGM2)
      RNM = EXP(ALOG(RVM)-3.*ALSGM2)
      TA = 2.*ALSGM2
      CN = 1./(SQRT(TWOPI)*ALSIGM)
      CS = PI*CN*RNM**2*EXP(TA)
      CV = (4./3.)*PI*CN*RNM**3*EXP(4.5*ALSGM2)
      F1 = ALOG(30.*SQRT2*ALSIGM)
      F1 = F1/15.
      F1 = EXP(-F1)
      AA = ALOG(1./F1)
      F2 = 1./F1
      V1 = 1.
      V2 = 1.
      DO 20 I = 1,K
      V1 = V1*F1
      R(I) = RSM*V1
      ST(I) = ALGN(ALSGM2,RSM,R(I))*CS
      VT(I) = ALGN(ALSGM2,RVM,R(I))*CV
      XNT(I) = ALGN(ALSGM2,RNM,R(I))*CN
   20 DR(I) = AA
      R(KP1) = RSM
      ST(KP1) = ALGN(SIGM2, RSM,RSM)*CS
      VT(KP1) = ALGN(SIGM2,RVM,RSM)*CV
      XNT(KP1) = ALGN(SIGM2,RNM,RSM)*CN
      DR(KP1) = AA
      DO 21 I = KP2,ITWKP1
      V2 = V2*F2
      R(I) = RSM*V2
      ST(I) = ALGN(SIGM2,RSM,R(I))*CS
      VT(I) = ALGN(SIGM2,RVM,R(I))*CV
      DR(I) = AA
   21 XNT(I) = ALGN(SIGM2,RNM,R(I))*CN
C     DO THE INTEGRATION OVER THE DISTRIBUTIONS
      XNTOT = 0.
```

SUBROUTINE BSIZE

```
      STOT = 0.
      VTOT = 0.
      DO 30 I = 1,ITWKP1
      VTOT = VTOT + VT(I)*DR(I)
      STOT = STOT + ST(I)*DR(I)
      XNTOT = XNTOT + XNT(I)*DR(I)
   30 CONTINUE
 1000 FORMAT(1H ,10X,10E10.4)
  500 CONTINUE
      DO 40 IL = 1,NLAMB
      XLAM = LAMB(IL)
      WAVE = TWOPI/XLAM
      EXT = 0.
      SCAT = 0.
      ABS = 0.
      AVCOS = 0.
      DO 31 J = 1,NT
 31   PHASE(J)=0.
      DO 60 I = 1,ITWKP1
 60   AL(I)= ALOG(WAVE*R(I))
      DO 62 I=1,ITWKP1
      DO 61 J=3,110
  61  IF(AL(I).LE.ALALFA(J)) GO TO 63
  63  Q=ALALFA(J)-ALALFA(J-1)
      IF(AL(I).GE.ALALFA(110)) GO TO 160
      Z=(AL(I)-ALALFA(J-1))/Q
      QST=QS(J-1)+0.25*Z*((5.*QS(J)-3.0*QS(J-1)-QS(J-2)-QS(J+1))
     2+(QS(J-2)-QS(J-1)-QS(J)+QS(J+1))*Z)
      QEX=QE(J-1)+0.25*Z*((5.*QE(J)-3.0*QE(J-1)-QE(J-2)-QE(J+1))
     2+(QE(J-2)-QE(J-1)-QE(J)+QE(J+1))*Z)
      QGP=QG(J-1)+0.25*Z*((5.*QG(J)-3.0*QG(J-1)-QG(J-2)-QG(J+1))
     2+(QG(J-2)-QG(J-1)-QG(J)+QG(J+1))*Z)
      GO TO 161
  160 QEX=QE(110)
      QST=QS(110)
      QGP=QG(110)
  161 CONTINUE
      EXT=QEX*ST(I)*DR(I)+EXT
      SCAT=QST*ST(I)*DR(I)+SCAT
      ABS=(QEX-QST)*ST(I)*DR(I)+ABS
      AVCOS=AVCOS+QGP*ST(I)*DR(I)
C     WRITE(6,357)I,J,EXT,SCAT,ABS,AVCOS
  357 FORMAT(2(2X,I4),4(2X,E13.4))
   62 CONTINUE
      DO 64 K=1,NTHETA
      DO 65 I=1,ITWKP1
      DO 66 J=3,110
  66  IF(AL(I).LE.ALALFA(J)) GO TO 67
  67  Q=ALALFA(J)-ALALFA(J-1)
      IF(AL(I).GE.ALALFA(110))GO TO 162
      Z=(AL(I)-ALALFA(J-1))/Q
      STMT(I,K)=STMTX(J-1,K)+0.25*Z*((5.*STMTX(J,K)-3.*STMTX(J-1,K)-
     2STMTX(J-2,K)-STMTX(J+1,K))+(STMTX(J-2,K)-STMTX(J-1,K)-STMTX(J,K)
     3+STMTX(J+1,K))*Z)
      GO TO 163
  162 STMT(I,K)=STMTX(110,K)
  163 CONTINUE
      PHASE(K)=STMT(I,K)*XNT(I)*DR(I) + PHASE(K)
   65 CONTINUE
   64 CONTINUE
C       PRINT OUT THE RESULTS
      RWB = XLAM**2/(PI*SCAT)
      DUM(IL) = EXT/VTOT
      DUMA(IL) = ABS/VTOT
      DUMG(IL) = AVCOS/SCAT
      DO 36 I = 1,NT
   36 PDUM(IL,I)=PHASE(I)*RWB
   40 CONTINUE
      ITEST=ITEST + 1
      RFRT=RFR
      GO TO 24
    1 IF(IASD.GT.1) GO TO 2
C
C INTEGRATION FOR A SECTIONAL
C AEROSOL SIZE DISTRIBUTION
C
      NSEC=11
      GO TO 3
    2 NSEC=22
    3 DX=4./(FLOAT(NSEC)+1.)
      R(1)=0.005
      AL(1)=ALOG(WAVE*R(1))
      DO 4 I=1,NSEC
      R(I+1)=R(I)*10.**DX
    4 AL(I+1)=ALOG(WAVE*R(I+1))
      DXJ=DX/6.
      DO 11 IL=1,NLAMB
      DO 5 I=1,NSEC
      EXT=0.
      SCAT=0.
      AVCOS=0.
      LSR=1
      DO 6 J=1,7
      JJ=6*I-6+J
      DO 7 K=2,150
    7 IF(AL(JJ).LE.ALALFA(K)) GO TO 8
    8 Q=ALALFA(K)-ALALFA(K-1)
      Z=(AL(JJ)-ALALFA(K-1))/Q
      RA=R(JJ)*10.**DXJ
      QEXS=Z*(QE(K)-QE(K-1))+QE(K-1)
      QSTS=Z*(QS(K)-QS(K-1))+QS(K-1)
      QGPS=Z*(QG(K)-QG(K-1))+QG(K-1)
      REX=3./4.*QEXS/RA
      RST=3./4.*QSTS/RA
      RGP=3./4.*QGPS/RA
      IF(LSR.GT.1) GO TO 23
      EXT=REX+EXT
      SCAT=RST+SCAT
      AVCOS=RGP+AVCOS
      LSR=4
   23 IF(LSR.GT.2) GO TO 22
      EXT=2.*REX+EXT
      SCAT=2.*RST+SCAT
      AVCOS=2.*RGP+AVCOS
      LSR=2
      GO TO 6
```

SUBROUTINE BSIZE

```
   22 EXT=4.*REX+EXT
      SCAT=4.*RST+SCAT
      AVCOS=4.*RGP+AVCOS
      LSR=2
      IF(J.EQ.6) LSR=1
    6 CONTINUE
      DOM(IL,I)=EXT/3.*DXJ
      DOMA(IL,I)=(EXT-SCAT)/3.*DXJ
      SCAT=SCAT/3.*DXJ
      DOMG(IL,I)=AVCOS/3.*DXJ/SCAT
      DO 12 J=1,NT
   12 PHASE(J)=0.
      DO 13 KK=1,NT
      LSR=1
      DO 14 J=1,7
      JJJ=6*I-6+J
      DO 15 K=2,150
   15 IF(AL(JJ).LE.ALALFA(K)) GO TO 16
   16 Q=ALALFA(K)-ALALFA(K-1)
      Z=(AL(JJ)-ALALFA(K-1))/Q
      RA=R(JJ)*10.**DXJ
      STMTS(KK)=Z*(STMTX(K,KK)-STMTX(K-1,KK))+STMTX(K-1,KK)
      RTMTS(KK)=STMTS(KK)*3./4./RA**3
      IF(LSR.GT.1) GO TO 17
      PHASE(KK)=PHASE(KK)+RTMTS(KK)
      LSR=4
      GO TO 14
   17 IF(LSR.GT.2) GO TO 19
      PHASE(KK)=PHASE(KK)+2.*RTMTS(KK)
      LSR=2
      GO TO 14
   19 PHASE(KK)=PHASE(KK)+4.*RTMTS(KK)
      IF(J.EQ.6) LSR=1
   14 CONTINUE
      PDOM(IL,I,KK)=PHASE(KK)/3.*DXJ*LAMB(IL)**2/(PI*SCAT)
   13 CONTINUE
    5 CONTINUE
   11 CONTINUE
   24 RETURN
      END
PROGRAM SIZE:   PROCEDURE - 004124    LINKAGE - 157356    STACK - 000054
0000 ERRORS [<BSIZE >FTN-REV18.2]
```

SUBROUTINE SOLARZ(SLA,SLO,TZ,IY,IM,ID,TIME,D,NV)

```
      SUBROUTINE SOLARZ(SLA,SLO,TZ,IY,IM,ID,TIME,D,NV)
C***
C***     SLA...  LATITUDE (DEG)  SOUTH = MINUS
C***     SLO...  LONGITUDE (DEG)  EAST = MINUS
C***     TZ...  TIME ZONE
C***            ALSO INCLUDES FRACTION IF LOCAL TIME IS NOT
C***             STANDARD MERIDIAN TIME.  E.G. POONA, INDIA 5.5
C***     IY..  YEAR
C***     IM..  MONTH
C***     ID..  DAY
C***     TIME.. LOCAL STANDARD TIME IN HOURS AND MINUTES.
C***            1 30 PM = 1330  ** STANDARD TIME **
C***     D..  RETURNED VALUE
C***     NV..  VALUE TO BE RETURNED, SELECTED AS FOLLOWS....
C***           1...  DECLINATION (DEG.)
C***           2...  EQUATION OF TIME ADJUSTMENT (HRS.)
C***           3...  TRUE SOLAR TIME (HRS.)
C***           4...  HOUR ANGLE (DEG.)
C***           5...  SOLAR ELEVATION (DEG.)
C***           6...  OPTICAL AIRMASS
C***     0 ( NV ( 7.  OTHERWISE, D = 9999.
C***
      COMMON /SOL/ EFFDEC, HRANGL
      DIMENSION MD(11)
      DOUBLE PRECISION RAD,SDEC
      DATA MD/31,29,31,30,31,30,2*31,30,31,30/
      DATA A,B,C,SIGA/0.15,3.885,1.253,279.9348/
      RAD=572957.75913E-4
      SDEC=39784.988432E-5
      RE=1.
      IF (SLO.LT.0.) RE=-1.
      KZ=TZ
      TC=(TZ-FLOAT(KZ))*RE
      TZZ=FLOAT(KZ)*RE
      SLB=SLA/RAD
      K=ID
      TIMH=TIME/100.
      I=TIMH
      TIMLOC=(TIMH-FLOAT(I))/0.6+FLOAT(I)+TC
      IMC=IM-1
      IF (IMC.LT.1) GO TO 10
      DO 5 I=1,IMC
    5 K=K+MD(I)
   10 LEAP=1
      NL=MOD(IY,4)
      IF (NL.LT.1) LEAP=2
      SMER=TZZ*15.
      TK=((SMER-SLO)*4.)/60.
      KR=1
      IF (K.GE.61.AND.LEAP.LT.2) KR=2
      DAD=(TIMLOC+TZZ)/24.
      DAD=DAD+FLOAT(K)-FLOAT(KR)
      DF=DAD*360./365.242
      DE=DF/RAD
      DESIN=SIN(DE)
      DECOS=COS(DE)
      DESIN2=SIN(DE*2.)
      DECOS2=COS(DE*2.)
```

```
SUBROUTINE SOLARZ(SLA,SLO,TZ,IY,IM,ID,TIME,D,NV)

      SIG=SIGA+DF+1.914827*DESIN-0.079525*DECOS+0.019938*DESIN2-0.00162*
     1DECOS2
      SIG=SIG/RAD
      DECSIN=SDEC*SIN(SIG)
      EFFDEC=ASIN(DECSIN)
      IF (NV.NE.1) GO TO 15
      D=EFFDEC*RAD
      RETURN
   15 EQT=0.12357*DESIN-0.004289*DECOS+0.153809*DESIN2+0.060783*DECOS2
      IF (NV.NE.2) GO TO 20
      D=EQT
      RETURN
   20 TST=TK+TIMLOC-EQT
      IF (NV.NE.3) GO TO 25
      D=TST
      IF (D.LT.0.) D=D+24.
      IF (D.GE.24.) D=D-24.
      RETURN
   25 HRANGL=ABS(TST-12.)*15.
      IF (NV.NE.4) GO TO 30
      D=HRANGL
      RETURN
   30 HRANGL=HRANGL/RAD
      SOLSIN=DECSIN*SIN(SLB)+COS(EFFDEC)*COS(SLB)*COS(HRANGL)
      SOLEL=ASIN(SOLSIN)*RAD
      IF (NV.NE.5) GO TO 35
      D=SOLEL
      RETURN
   35 IF (NV.NE.6) GO TO 40
      IF (SOLEL.LE.0.) GO TO 40
      TK=SOLEL+B
      E=1./TK**C
      D=1./(A*E+SOLSIN)
      RETURN
   40 D=9999.
      RETURN
      END
PROGRAM SIZE:   PROCEDURE - 001066    LINKAGE - 000176    STACK - 000106
0000 ERRORS [<SOLARZ>FTN-REV18.2]
```

SUBROUTINE SPLNA (N,X,Y,J,D,C,W)

```
       SUBROUTINE SPLNA (N,X,Y,J,D,C,W)
       DIMENSION X(10), Y(10), D(2), C(30), W(30)
C      ---------------------------------------------------------------
C             OVER THE INTERVAL X(I) TO X(I+1), THE INTERPOLATING
C             POLYNOMIAL
C                  Y=Y(I)+A(I)*Z+B(I)*Z**2+E(I)*Z**3
C             WHERE Z=(X-X(I))/(X(I+1)-X(I))
C             IS USED. THE COEFFICIENTS A(I),B(I) AND E(I) ARE COMPUTED
C             BY SPLNA AND STORED IN LOCATIONS C(3*I-2),C(3*I-1) AND
C             C(3*I) RESPECTIVELY.
C             WHILE WORKING IN THE ITH INTERVAL,THE VARIABLE Q WILL
C             REPRESENT Q=X(I+1) - X(I), AND Y(I) WILL REPRESENT
C             Y(I+1)-Y(I)
C      ---------------------------------------------------------------
C
      Q=X(2)-X(1)
      YI=Y(2)-Y(1)
      IF (J.EQ.2) GO TO 5
C      ---------------------------------------------------------------
C             IF THE FIRST DERIVATIVE AT THE END POINTS IS GIVEN,
C             A(1) IS KNOWN, AND THE SECOND EQUATION BECOMES
C             MERELY B(1)+E(1)=YI - Q*D(1).
C      ---------------------------------------------------------------
      C(1)=Q*D(1)
      C(2)=1.0
      W(2)=YI-C(1)
      GO TO 10
C      ---------------------------------------------------------------
C             IF THE SECOND DERIVATIVE AT THE END POINTS IS GIVEN
C             B(1) IS KNOWN, THE SECOND EQUATION BECOMES
C             A(1)+E(1)=YI-0.5*Q*Q*D(1). DURING THE SOLUTION OF
C             THE 3N-4 EQUATIONS,A1 WILL BE KEPT IN CELL C(2)
C             INSTEAD OF C(1) TO RETAIN THE TRIDIAGONAL FORM OF THE
C             COEFFICIENT MATRIX.
C      ---------------------------------------------------------------
    5 C(2)=0.0
      W(2)=0.5*Q*Q*D(1)
   10 M=N-2
      IF (M.LE.0) GO TO 20
C      ---------------------------------------------------------------
C             UPPER TRIANGULARIZATION OF THE TRIDIAGONAL SYSTEM OF
C             EQUATIONS FOR THE COEFFICIENT MATRIX FOLLOWS--
C      ---------------------------------------------------------------
      DO 15 I=1,M
      AI=Q
      Q=X(I+2)-X(I+1)
      H=AI/Q
      C(3*I)=-H/(2.0-C(3*I-1))
      W(3*I)=(-YI-W(3*I-1))/(2.0-C(3*I-1))
      C(3*I+1)=-H*H/(H-C(3*I))
      W(3*I+1)=(YI-W(3*I))/(H-C(3*I))
      YI=Y(I+2)-Y(I+1)
      C(3*I+2)=1.0/(1.0-C(3*I+1))
   15 W(3*I+2)=(YI-W(3*I+1))/(1.0-C(3*I+1))
C      ---------------------------------------------------------------
C             E(N-1) IS DETERMINED DIRECTLY FROM THE LAST EQUATION
C             OBTAINED ABOVE, AND THE FIRST OR SECOND DERIVATIVE
C             VALUE GIVEN AT THE END POINT.
```

SUBROUTINE SPLNA (N,X,Y,J,D,C,W)

```
C     ----------------------------------------------------------------
   20 IF (J.EQ.1) GO TO 25
      C(3*N-3)=(Q*Q*D(2)/2.0-W(3*N-4))/(3.0-C(3*N-4))
      GO TO 30
   25 C(3*N-3)=(Q*D(2)-YI-W(3*N-4))/(2.0-C(3*N-4))
   30 M=3*N-6
      IF (M.LE.0) GO TO 40
C     ----------------------------------------------------------------
C              BACK SOLUTION FOR ALL COEFFICENTS EXCEPT
C              A(1) AND B(1) FOLLOWS--
C     ----------------------------------------------------------------
      DO 35 II=1,M
      I=M-II+3
   35 C(I)=W(I)-C(I)*C(I+1)
   40 IF (J.EQ.1) GO TO 45
C     ----------------------------------------------------------------
C              IF THE SECOND DERIVATIVE IS GIVEN AT THE END POINTS,
C              A(1) CAN NOW BE COMPUTED FROM THE KNOWN VALUES OF
C              B(1) AND E(1). THEN A(1) AND B(1) ARE PUT INTO THEIR
C              PROPER PLACES IN THE C ARRAY.
C     ----------------------------------------------------------------
      C(1)=Y(2)-Y(1)-W(2)-C(3)
      C(2)=W(2)
      RETURN
   45 C(2)=W(2)-C(3)
      RETURN
      END
PROGRAM SIZE:   PROCEDURE - 001140    LINKAGE - 000036    STACK - 000110
0000 ERRORS [<SPLNA >FTN-REV18.2]
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SUBROUTINE VVGTU1

```
      SUBROUTINE VVGTU1
C
C     *** SETS UP COEFFICIENTS FOR CONVERTING GEODETIC TO
C         RECTIFYING LATITUDE AND CONVERSELY
C
C         A1-A4 COEFFICIENTS FOR CONVERTING GEODITIC TO RECTIFYING LATIT
C         A5    FALSE EASTING
C         A6    FALSE NORTHING
C         A8    SCALE FACTOR AT CENTRAL MERIDIAN
C         A9    CENTRAL MERIDIAN IN SECONDS
C         A10   RADIUS OF SPHERE HAVING GREAT CIRCLE LENGTH EQUAL TO
C               SPHEROID MERIDIAN LENGTH
C         A11-A14  COEFFICIENTS FOR CONVERTING RECTIFYING LATITUDE TO
C                  GEODETIC LATITUDE
C         A15   SEMIMAJOR AXIS OF SPHERIOD
C         A16   ECCENTRICITY SQUARED
C
C
      COMMON /VVUTM/ A(16)
      DATA IFRST/1/
C
C     *** COMPUTE COEFFICIENTS ON FIRST PASS ONLY
      IF (IFRST .NE. 1) RETURN
      IFRST = 0
C
      A(5)=5.0E5
      A(6)=0.0
      A(7)=0.0
      A(8)=0.9996
C
C     *** CLARKE 1866 ELLIPSOID AXES LENGTHS
      A(15)=6378206.4
      B = 6356583.80
C
      A(16)= ((A(15)-B)/A(15))*((A(15)+B)/A(15))
      A(10)=(((A(16)*(7.0/3.2E1)+(5.0/1.6E1))*A(16)+0.5)*A(16)
     1 +1.0)*A(16)*0.25
      A(1)=-(((A(10)*(1.95E2/6.4E1)+3.25)*A(10)+3.75)*A(10)+3.0)*
     1 A(10)
      A(2)=(((1.455E3/3.2E1)*A(10)+(7.0E1/3.0))*A(10)+7.5)*A(10)**2
      A(3)=-((7.0E1/3.0)+A(10)*(9.45E2/8.0))*A(10)**3
      A(4)=(3.15E2/4.0)*A(10)**4
      A(11)=(((7.75-(6.57E2/6.4E1)*A(10))*A(10)-5.25)*A(10)+3.0)*
     1 A(10)
      A(12)=(((5.045E3/3.2E1)*A(10)-(1.51E2/3.0))*A(10)+10.5)*
     1 A(10)**2
      A(13)=((1.51E2/3.0)-(3.291E3/8.0)*A(10))*A(10)**3
      A(14)=(1.097E3/4.0)*A(10)**4
      FAC=A(10)*A(10)
      A(10)=(((2.25E2/6.4E1)*FAC+2.25)*FAC+1.0)*(1.0-FAC)*
     1 (1.0-A(10))*A(15)
      RETURN
      END
PROGRAM SIZE:   PROCEDURE - 000456     LINKAGE - 000066     STACK - 000046
0000 ERRORS [<VVGTU1>FTN-REV18.2]
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SUBROUTINE MAPUTG (UTMX,UTMY,IZONE,ALON,ALAT)

```
      SUBROUTINE MAPUTG (UTMX,UTMY,IZONE,ALON,ALAT)
C
C     *** CONVERTS UTM COORDINATES TO LATITUDE AND LONGITUDE
C         THIS IS A MODIFICATION OF THE US GEOLOGICAL SURVEY
C         PROGRAM NO J380  (TOPOGRAPHIC DIVISION)
C             GW LUNDBERG/SAI  APR 79
C
C         UTMX    EASTING IN KILOMETERS
C         UTMY    NORTHING IN KILOMETERS
C         IZONE   UTM ZONE NUMBER
C         ALON    LONGITUDE IN DEGREES
C         ALAT    LATITUDE IN DEGREES
C
      DIMENSION B(12)
      COMMON /VVUTM/ A(16)
C
      X = UTMX*1000.
      Y = UTMY*1000.
C
C     *** COMPUTE CONVERSION COEFFICIENTS IF NEEDED
      CALL VVGTU1
C
C     *** COMPUTE CENTRAL MERIDIAN IN SECONDS FROM IZONE INPUT
   10 UTZ = 30.0 - FLOAT(IABS (IZONE))
      A(9) = ((UTZ*6.0) + 3.0) * 3600.0
C
C     *** CONVERT UTM COORDINATES TO GEODETIC
      B(9)=((A(5)-X)*1.0E-6)/A(8)
      IF (ABS(B(9))-1.0E-7*A(15)*2.0)30,30,20
   20 SLAT=0.0
      SLON=0.0
      GO TO 99
   30 B(10)=((Y-A(6))/A(8)+A(7))/A(10)
      IF(ABS(B(10))-1.47E0)40,40,20
   40 SINW=SIN(B(10))
      COSW=COS(B(10))
      B(12)=COSW*COSW
      B(11)=(((A(14)*B(12)+A(13))*B(12)+A(12))*B(12)+A(11))*SINW*COSW
     1 +B(10)
      SINW=SIN(B(11))
      COSW=COS(B(11))
      RN=SQRT(1.0-A(16)*SINW*SINW)*1.0E6/A(15)
      T=SINW/COSW
      TS=T*T
      B(12)=COSW*COSW
      ETAS=A(16)*B(12)/(1.0-A(16))
      B(1)=RN/COSW
      B(2)=-T*(1.0+ETAS)*RN*RN/2.0
      B(3)=-(1.0+2.0*TS+ETAS)*B(1)*RN*RN/6.0
      B(4)=(((-6.0-ETAS*9.0)*ETAS+3.0)*TS+(6.0-ETAS*3.0)*ETAS
     1 +5.0)*T*RN**4/24.0
      B(5)=((TS*24.0+ETAS*8.0+28.0)*TS+ETAS*6.0+5.0)*B(1)*
     1 RN**4/120.0
      B(6)=(((ETAS*45.0-45.0)*TS+ETAS*162.0-90.0)*TS
     1 -ETAS*107.0-61.0)*T*RN**6/720.0
      B(7)=-(((TS*720.0+1320.0)*TS+662.0)*TS+61.0)*B(1)*RN**6/
     1 5040.0
      B(8)=(((TS*1575.0+4095.0)*TS+3633.0)*TS+1385.0)*T*RN**8/
     1 40320.0
      B(10)=B(9)*B(9)
      SLAT=((((B(8)*B(10)+B(6))*B(10)+B(4))*B(10)+B(2))*B(10)+B(11))*
     1 206264.80624709
      SLON= (((B(7)*B(10)+B(5))*B(10)+B(3))*B(10)+B(1))*B(9)*
     1 206264.80624709 + A(9)
C
C     *** CONVERT SECONDS OF ARC TO DEGREES AND RETURN
   99 ALAT = SLAT/3600.
      ALON = -SLON/3600.
C
      RETURN
      END
PROGRAM SIZE:   PROCEDURE - 001034    LINKAGE - 000142    STACK - 000070
0000 ERRORS [<MAPUTG>FTN-REV18.2]
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```
      SUBROUTINE DAMIE (X,RFR,RFI,THETD,JX,QEXT,QSCAT,CTBRQS,ELTRMX,
     1 PI,TAU,CSTHT,SI2THT,ACAP,IT,LL)
C      LARGE VERSION
C      SUBROUTINE FOR COMPUTING THE PARAMETERS OF THE ELECTROMAGNETIC
C      RADIATION SCATTERED BY A SPHERE. THIS SUBROUTINE CARRIES OUT ALL
C      COMPUTATIONS IN DOUBLE PRECISION ARITHMETIC.
C      THIS SUBROUTINE COMPUTES THE CAPITAL A FUNCTION BY MAKING USE OF
C      DOWNWARD RECURRENCE RELATIONSHIP.
C      X! SIZE PARAMETER OF THE SPHERE,( 2 * PI * RADIUS OF THE SPHERE)
C      WAVELENGTH OF THE INCIDENT RADIATION).
C      RF! REFRACTIVE INDEX OF THE MATERIAL OF THE SPHERE.  COMPLEX
C      QUANTITY..FORM! (RFR - I * RFI )
C      THETD(J)! ANGLE IN DEGREES BETWEEN THE DIRECTIONS OF THE INCIDENT
C      AND THE SCATTERED RADIATION.  THETD(J) IS< OR= 90.0
C      IF THETD(J) SHOULD HAPPEN TO BE GREATER THAN 90.0, ENTER WITH
C      SUPPLEMENTARY VALUE
CSEE COMMENTS BELOW ON ELTRMX.
C      JX! TOTAL NUMBER OF THETD FOR WHICH THE COMPUTATIONS ARE
C      REQUIRED.  JX SHOULD NOT EXCEED IT UNLESS THE DIMENSIONS
C      STATEMENTS ARE APPROPRIATEDLY MODIFIED.
C      MAIN PROGRAM SHOULD ALSO HAVE REAL*8 THETD(IT ),ELTRMX(4,IT ,2).
C      THE DEFINITIONS FOR THE FOLLOWING SYMBOLS CAN BE FOUND IN       LIGHT
       REAL   X,RX,RFR,RFI,QEXT,QSCAT,T(5),TA(4),TB(2),TC(2)
       REAL   TD(2),TE(2),CTBRQS
       REAL   ELTRMX(4,IT ,2),PI(3,IT ),TAU(3,IT ),CSTHT(IT ),SI2THT(IT)
     1 ,THETD(IT)
       COMPLEX     RF,RRF,RRFX,WM1,FNA,FNB,TC1,TC2,WFN(2)
       COMPLEX     FNAP,FNBP,ACAP(1)
C      IN THE ORIGINAL PROGRAM THE DIMENSION OF ACAP WAS 7000.
C      FOR CONSERVING SPACE THIS SHOULD BE NOT MUCH HIGHER THAN
C      THE VALUE, N=1.1*(NREAL**2 + NIMAG**2)**.5 * X + 1
C      TA(1)! REAL PART OF WFN(1).. TA(2)! IMAGINARY PART OF WFN(1)..
C      TA(3)! REAL PART OF WFN(2)..TA(4)! IMAGINARY PART OF WFN(2).
C      TB(1)! REAL PART OF FNA.. TB(2)! IMAGINARTY PART OF FNA..
C      TC(1)! REAL PART OF FNB.. TC(2)! IMAGINARY PART OF FNB..
C      TD(1)! REAL PART OF FNAP..TD(2) IMAGINARY PART OF FNAP.
C      TE(1)! REAL PART OF FNBP.. TE(2)! IMAGINARY PART OF FNBP.
C     FNAP ? FNBP ARE THE PRECEDING VALUES OF FNA ? FNB RESPECTIVELY.
C**** PRIME VERSION WORKS ONLY IN SINGLE PRECISION WITH THE
C     COMPLEX ARITHMETIC.
       EQUIVALENCE (WFN(1),TA(1)),(FNA,TB(1)),(FNB,TC(1))
       EQUIVALENCE(FNAP,TD(1)),(FNBP,TE(1))
      DATA PII /3.1415926535897932/
C
C     FORMAT STATEMENTS FOLLOW
 5     FORMAT(10X,' THE VALUE OF THE SCATTERING ANGLE IS GREATER THAN
     1 90.0 DEGREES. IT IS ',E15.4)
 6     FORMAT(//10X, 'PLEASE READ COMMENTS.' //)
 7     FORMAT(//10X,'THE VALUE OF THE ARGUMENT JX IS GREATER THAN IT ')
 8     FORMAT(//10X,'THE UPPER LIMIT FOR ACAP IS NOT ENOUGH. SUGGEST GET
     1 DETAILED OUPUT AND MODIFY SUBROUTINE'//)
C
C     EXECUTABLE STATEMENTS FOLLOW
       IF(JX.LE. IT) GO TO 20
       WRITE(6,7)
       WRITE(6,6)
       CALL EXIT
 20    RF =  CMPLX(RFR,-RFI)
```

```
      RRF = 1.0E0/RF
      RX = 1.0E0/X
      RRFX = RRF * RX
      T(1) = (X**2)*(RFR**2 + RFI**2)
      T(1) =  SQRT(T(1))
      NMX1 = 1.10E0 * T(1)
C     WRITE(6,199) X,RFR,RFI,LL,NMX1
C 199 FORMAT(1H ,'X=',E14.6,2X,'RFR=',E14.6,2X,'RFI=',E14.6,2X,'LL=',I10
C    1,2X,*NMX1                                  *,I10)
      IF( NMX1 .LE. LL-1 ) GO TO 21
      WRITE(6,8)
      STOP
 21   NMX2 = T(1)
      IF( NMX1 .GT. 150) GO TO 22
      NMX1 = 150
      NMX2 = 135
 22   ACAP(NMX1 + 1 ) = (0.0E0,0.0E0)
      DO 23 N = 1,NMX1
      NN = NMX1 - N + 1
      ACAP(NN)=FLOAT(NN+1)*RRFX-1.0E0/(FLOAT(NN+1)*RRFX+ACAP(NN+1))
 23   CONTINUE
      DO 30 J = 1,JX
      IF ( THETD(J) .LT. 0.0E0 ) THETD(J) =  ABS(THETD(J))
      IF ( THETD(J) .GT. 0.0E0 ) GO TO 24
      CSTHT(J) = 1.0E0
      SI2THT(J) = 0.0E0
      GO TO 30
 24   IF ( THETD(J) .GE. 90.0E0) GO TO 25
      T(1) = ( PII * THETD(J))/180.0E0
      CSTHT(J) =  COS(T(1))
      SI2THT(J) = 1.0E0 - CSTHT(J)**2
      GO TO 30
 25   IF ( THETD(J) .GT. 90.0E0) GO TO 28
      CSTHT(J) = 0.0E0
      SI2THT(J) = 1.0E0
      GO TO 30
 28   WRITE(6,5) THETD(J)
      WRITE(6,6)
      CALL EXIT
 30   CONTINUE
      DO 35 J = 1,JX
      PI(1,J) = 0.0E0
      PI(2,J) = 1.0E0
      TAU(1,J) = 0.0E0
      TAU(2,J) = CSTHT(J)
 35   CONTINUE
      T(1) =  COS(X)
      T(2) =  SIN(X)
      WM1 =  CMPLX( T(1),-T(2))
      WFN(1) =  CMPLX(T(2),T(1))
      WFN(2) = RX * WFN(1) - WM1
      TC1 = ACAP(1) * RRF + RX
      TC2 = ACAP(1) * RF + RX
      FNA = (TC1*TA(3) - TA(1))/(TC1*WFN(2) - WFN(1))
      FNB = ( TC2*TA(3) - TA(1))/(TC2  * WFN(2) - WFN(1))
      FNAP = FNA
      FNBP = FNB
      T(1) = 1.50E0
```

```
C         FROM HERE TO THE STATMENT NUMBER 90, ELTRMX(I,J,K) HAS
C         FOLLOWING MEANING!
C         ELTRMX(1,J,K)! REAL PART OF THE FIRST COMPLEX AMPLITUDE.
C         ELTRMX(2,J,K)! IMAGINARY PART OF THE FIRST COMPLEX AMPLITUDE.
C         ELTRMX(3,J,K)! REAL PART OF THE SECOND COMPLEX AMPLITUDE.
C         ELTRMX(4,J,K)! IMAGINARY PART OF THE SECOND COMPLEX AMPLITUDE.
C         K = 1 ! FOR THETD(J) AND K = 2 ! FOR 180.0 - THETD(J)
C         DEFINITION OF THE COMPLEX AMPLITUDE! VAN DE HULST,P.125.
          TB(1) = T(1) * TB(1)
          TB(2) = T(1) * TB(2)
          TC(1) = T(1) * TC(1)
          TC(2) = T(1) * TC(2)
          DO 60 J = 1,JX
          ELTRMX(1,J,1) = TB(1) * PI(2,J) + TC(1) * TAU(2,J)
          ELTRMX(2,J,1) = TB(2) * PI(2,J) + TC(2) * TAU(2,J)
          ELTRMX(3,J,1) = TC(1) * PI(2,J) + TB(1) * TAU(2,J)
          ELTRMX(4,J,1) = TC(2) * PI(2,J) + TB(2) * TAU(2,J)
          ELTRMX(1,J,2) = TB(1) * PI(2,J) - TC(1) * TAU(2,J)
          ELTRMX(2,J,2) = TB(2) * PI(2,J) - TC(2) * TAU(2,J)
          ELTRMX(3,J,2) = TC(1) * PI(2,J) - TB(1) * TAU(2,J)
          ELTRMX(4,J,2) = TC(2) * PI(2,J) - TB(2) * TAU(2,J)
  60      CONTINUE
          QEXT = 2.0E0 * ( TB(1) + TC(1))
C        WRITE(6,999) TB(1),TC(1)
          QSCAT =(TB(1)**2 + TB(2)**2 + TC(1)**2 + TC(2)**2)/0.75E0
          CTBRQS = 0.0E0
          N = 2
  65      T(1) = 2*N - 1
          T(2) = N - 1
          T(3) = 2 * N + 1
          DO 70 J = 1,JX
          PI(3,J) = (T(1)*PI(2,J)*CSTHT(J)-FLOAT(N)*PI(1,J))/T(2)
          TAU(3,J) = CSTHT(J)*(PI(3,J)-PI(1,J))-T(1)*SI2THT(J)*PI(2,J)+
        1 TAU(1,J)
  70      CONTINUE
          WM1 = WFN(1)
          WFN(1) = WFN(2)
          WFN(2) = T(1)*RX*WFN(1) - WM1
          TC1 = ACAP(N)*RRF + FLOAT(N)*RX
          TC2 = ACAP(N)*RF + FLOAT(N)*RX
          FNA = (TC1*TA(3)-TA(1))/(TC1*WFN(2) - WFN(1))
         TC2 = TC2
         TA(3) = TA(3)
         TA(1) = TA(1)
         TC1 = TC1
         WFN(2) = WFN(2)
         WFN(1) = WFN(1)
          FNB = (TC2*TA(3)-TA(1))/(TC2*WFN(2) - WFN(1))
          T(5) = N
          T(4) = T(1)/(T(5)*T(2))
          T(2) = (T(2)*(T(5) + 1.0E0))/T(5)
          CTBRQS = CTBRQS + T(2)*(TD(1)*TB(1) + TD(2)*TB(2) + TE(1)*TC(1) +
        1 TE(2)*TC(2))  + T(4)*(TD(1)*TE(1) + TD(2)*TE(2))
          QEXT = QEXT + T(3)*(TB(1)+TC(1))
          T(4) = TB(1)**2 + TB(2)**2 + TC(1)**2 + TC(2)**2
          QSCAT = QSCAT + T(3) *T(4)
          T(2) = N*(N+1)
          T(1) = T(3)/T(2)
```

```
C     WRITE(6,999) T(1),QEXT
      K = (N/2)*2
       DO 80 J = 1,JX
       ELTRMX(1,J,1)=ELTRMX(1,J,1)+T(1)*(TB(1)*PI(3,J)+TC(1)*TAU(3,J))
       ELTRMX(2,J,1)=ELTRMX(2,J,1)+T(1)*(TB(2)*PI(3,J)+TC(2)*TAU(3,J))
       ELTRMX(3,J,1)=ELTRMX(3,J,1)+T(1)*(TC(1)*PI(3,J)+TB(1)*TAU(3,J))
       ELTRMX(4,J,1)=ELTRMX(4,J,1)+T(1)*(TC(2)*PI(3,J)+TB(2)*TAU(3,J))
       IF ( K .EQ. N) GO TO 75
      ELTRMX(1,J,2)=ELTRMX(1,J,2) +T(1)*(TB(1)*PI(3,J)-TC(1)*TAU(3,J))
       ELTRMX(2,J,2)=ELTRMX(2,J,2)+T(1)*(TB(2)*PI(3,J)-TC(2)*TAU(3,J))
       ELTRMX(3,J,2)=ELTRMX(3,J,2)+T(1)*(TC(1)*PI(3,J)-TB(1)*TAU(3,J))
       ELTRMX(4,J,2)=ELTRMX(4,J,2)+T(1)*(TC(2)*PI(3,J)-TB(2)*TAU(3,J))
       GO TO 80
 75    ELTRMX(1,J,2)=ELTRMX(1,J,2)+T(1)*(-TB(1)*PI(3,J)+TC(1)*TAU(3,J))
       ELTRMX(2,J,2)=ELTRMX(2,J,2)+T(1)*(-TB(2)*PI(3,J)+TC(2)*TAU(3,J))
       ELTRMX(3,J,2)=ELTRMX(3,J,2)+T(1)*(-TC(1)*PI(3,J)+TB(1)*TAU(3,J))
       ELTRMX(4,J,2)=ELTRMX(4,J,2)+T(1)*(-TC(2)*PI(3,J)+TB(2)*TAU(3,J))
 80    CONTINUE
       IF( T(4) .LT.  1.0E-6 ) GO TO 100
       N = N + 1
       DO 90 J = 1,JX
       PI(1,J) = PI(2,J)
       PI(2,J) = PI(3,J)
       TAU(1,J) = TAU(2,J)
       TAU(2,J) = TAU(3,J)
 90    CONTINUE
       FNAP = FNA
       FNBP = FNB
       IF ( N .LE. NMX2) GO TO 65
       WRITE(6,8)
       CALL EXIT
 100   DO 120 J = 1,JX
       DO 120 K = 1,2
       DO  115  I= 1,4
       T(I) = ELTRMX(I,J,K)
 115   CONTINUE
       ELTRMX(2,J,K) = T(1)**2 + T(2)**2
       ELTRMX(1,J,K) = T(3)**2 + T(4)**2
       ELTRMX(3,J,K) = T(1)*T(3) + T(2)*T(4)
       ELTRMX(4,J,K) = T(2)*T(3) - T(4)*T(1)
 120   CONTINUE
       T(1) = 2.0E0 * RX**2
       QEXT = QEXT * T(1)
C     WRITE(6,999) T(1),QEXT
C999    FORMAT(1H ,3E20.8)
       QSCAT = QSCAT * T(1)
       CTBRQS = 2.E0 * CTBRQS * T(1)
C      THE DETAIL ABOUT THIS SUBROUTINE CAN BE FOUND IN THE FOLLOWING
C      REPORT!
C                                               SUBROUTINES FOR COMPUTING THE PARAM
C      ELECTROMAGNETIC RADIATION SCATTERED BY A SPHERE                        J.V. DA
C      I B M SCIENTIFIC CENTER, PALO ALTO , CALIFORNIA.
C      REPORT NO. 320 - 3236 .. MAY 1968 ..
 99999 RETURN
       END
PROGRAM SIZE:   PROCEDURE - 004542    LINKAGE - 000204    STACK - 000174
0000 ERRORS [<DAMIE >FTN-REV18.2]
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```
      SUBROUTINE PLMAX(ZENITH,BETA,THETA,ITHETA,CPAVE,CPSAVE,CNAVE,
     1 CARAVE,XALONG,SPECP,SPECB)
C
C   CALCULATE THE CHANGE IN SPECTRAL RADIANCE ALONG A SEGMENT OF THE
C   LINE OF SIGHT WITH SPECIFIED AVERAGE PLUME CONCENTRATIONS.
C
      COMMON/RADPRP/BTASO4(39),BTACOR(39),BTAPRM(39),BTAAER(39),
     1PAER(39,27),PPRIM(39,27),PSO4(39,27),PCOR(39,27),BTABAC(39)
     2,PCAR(39,27),ABSCAR(39),BTACAR(39),ABSSO4(39),ABSCOR(39),
     3 ABSPRM(39),GSO4(39),GCOR(39),GPRM(39),GCAR(39),GAER(39)
     4,GBAC(39),PBAC(39,27)
      COMMON/OPTDEP/TATOIZ(39),TATHIZ(39),TATOHZ(39),X1(39),
     1X2(39),TAUTDI(39),TAUTOD(39),XHDI(39),XHOD(39)
      COMMON/ MISC/ ABSNO2(39),SOLAR(39),RAD,FORPIN,OMZ(39),OMH(39)
     1,NTHETA,RFR,RFI
      COMMON/PLM/PPLM(39,27)
      DIMENSION SPECP(39),SPECB(39)
      DIMENSION GB(39),GP(39),X1I(39),TPTOTI(39),OMEGIP(39),TP1I(39)
      DIMENSION FDAVI(39),GI(39)
      TWOPI=.5/FORPIN
      RHO=.3
      RHOPI=0.5*RHO*TWOPI
      XMU0=COS(RAD*ZENITH)
      XMUR=SIN(BETA*RAD)
      XMU0=COS(ZENITH*RAD)
      COSTTA=COS(THETA*RAD)
      IF(BETA.EQ.90.)GO TO 30
      CDR=(COSTTA-XMUR*XMU0)/(SQRT(1.-XMU0**2)*
     2SQRT(1.-XMUR**2))
      GO TO 31
   30 IF(THETA.NE.ZENITH)GO TO 660
      DF=0.
      GO TO 32
   31 CONTINUE
      ACDR=ABS(CDR)
      IF(ACDR.GT.1.) GO TO 660
      DF=ACOS(CDR)/RAD
   32 CONTINUE
      PRAY=0.75*(1.+COS(RAD*THETA)**2)
      DO 50 I=1,39
         FD0=SOLAR(I)*EXP(-TATOIZ(I)/XMU0)
         FDH=SOLAR(I)*EXP(-TATHIZ(I)/XMU0)
         FDAV=(FD0+FDH)*0.5
         PTOTOD=XHOD(I)*PRAY+(1.-XHOD(I))*PAER(I,ITHETA)
         PTOTOD=PTOTOD*OMH(I)
C******
C***   COMPUTE THE PLUME TRANSMISSION
C*****
         TAUP1=BTABAC(I)*XALONG
         TAPSO4=BTASO4(I)*CPSAVE*XALONG
         TAPNO2=ABSNO2(I)*CNAVE*XALONG
         TAPRIM=BTAPRM(I)*CPAVE*XALONG + (BTACAR(I) + ABSCAR(I))*CARAVE*
     1   XALONG
         TAUP2=TAPSO4+TAPNO2+TAPRIM
         TAPTOT=TAUP1+TAUP2
         IF((TAPSO4+TAPRIM).EQ.0.0)GO TO 55
         XD2=TAPSO4/(TAPSO4+TAPRIM)
         XD3=(1.-XD2)*PLUMEP*FRACTC*BTACAR(I)/TAPRIM
```

```
             GO TO 60
   55        XD2=0.0
   60        IF(TAUP2.EQ.0.0)GO TO 65
             OMEGAP=1.-(TAPNO2+ABSCAR(I)*CARAVE*XALONG)/TAUP2
             GO TO 70
   65        OMEGAP=1.
   70        PTOTPL=XD2*PSO4(I,ITHETA)+(1.-XD2)*PPRIM(I,ITHETA)
         1   + XD3 * PCAR(I,ITHETA)
             TP1=EXP(-TAUP1)
             TP2=EXP(-TAUP2)
             TPTOT=EXP(-TAPTOT)
             PTOTOD=XHOD(I)*PRAY+(1.-XHOD(I))*PAER(I,ITHETA)
             PTOTOD=PTOTOD*OMH(I)
             IF(TAPTOT.EQ.0.0)GO TO 75
             X11=TAUP2/TAPTOT
             GO TO 80
   75        X11=0.0
   80        CONTINUE
          X1I(I) = X11
          TPTOTI(I) = TPTOT
          OMEGIP(I) = OMEGAP
          TP1I(I) = TP1
          FDAVI(I) = FDAV
          DO 252 J=1,7
          PPLM(I,J) = XD2*PSO4(I,J) + (1.-XD2)*PPRIM(I,J)
         2 + XD3*PCAR(I,J)
          PBAC(I,J) = XHOD(I)*PRAY + (1.-XHOD(I))*PAER(I,J)
      252 CONTINUE
       50 CONTINUE
          DF = 0.
          IPF = 0
          CALL INTEG(DF,BETA,IPF,GI)
          DO 253 I=1,39
      253 GB(I) = GI(I)
          IPF = 1
          CALL INTEG(DF,BETA,IPF,GI)
          DO 254 I=1,39
      254 GP(I) = GI(I)
          DO 255 I=1,39
          SPECP(I)=SPECP(I)*TPTOTI(I)+X1I(I)*OMEGIP(I)*FORPIN*
         1PPLM(I,ITHETA)*FDAVI(I)*(1.-TPTOTI(I))+(1.-X1I(I))*FORPIN
         2*PBAC(I,ITHETA)*FDAVI(I)*(1.-TPTOTI(I))
          DP = GB(I)*(1.-X1I(I))*(1.-TPTOTI(I)) + GP(I)*X1I(I)
         1 *OMEGIP(I)*(1.-TPTOTI(I))
             SPECP(I)=SPECP(I)+DP
          SPECB(I)=SPECB(I)*TP1I(I)+FORPIN*PBAC(I,ITHETA)*FDAVI(I)
         1*(1.-TP1I(I)) + GB(I)*(1.-TP1I(I))
C         WRITE(6,1000)I,SPECB(I),SPECP(I),GB(I),GP(I)
  255     CONTINUE
     1000 FORMAT(/,1X,I4,4(2X,E10.4))
      660 DO 61 I=1,39
          SPECB(I)=1.
       61 CONTINUE
          RETURN
          END
PROGRAM SIZE:   PROCEDURE - 001512    LINKAGE - 001370    STACK - 000124
0000 ERRORS [<PLMAX >FTN-REV18.2]
```

FUNCTION CLOCK(T1,IINC)

```
           FUNCTION CLOCK(T1,IINC)
C
C    ****    ADD A TIME IN MINUTES TO A 2400 HOUR TIME AND RETURN A 2400
C    ****    HOUR TIME
C
      T2 = IINC
      I100 = INT(T1/100.)
      T3 = T1-100.0*FLOAT(I100) + T2
      I100 = I100 + INT(T3/60.)
      CLCK=FLOAT(I100)*100.0 + T3 -60.0 * FLOAT(INT(T3/60.))
      T4=CLCK-FLOAT(IFIX(CLCK) /100)*100.
      CLOCK=CLCK
      IF(T4.GT.59.) CLOCK=CLCK-40.
      RETURN
      END
PROGRAM SIZE:   PROCEDURE - 000136    LINKAGE - 000034    STACK - 000054
0000 ERRORS [<CLOCK >FTN-REV18.2]
```

SUBROUTINE PLMIN(RPR,ROR,SY,RP,YINTR)

```
      SUBROUTINE PLMIN(RPR,ROR,SY,RP,YINTR)
C
C     SUBROUTINE TO RECALCULATE PLUME CENTROID WHEN OBSERVER OR BACKGROUND
C     OBJECT IS WITHIN THE PLUME.
C
      YINTRF=0.5
      YINTRB=0.5
      YINTR=YINTRF+YINTRB
      IF(RPR.LT.2.17.AND.ROR.GT.2.17)GO TO 10
      IF(RPR.GT.2.17.AND.ROR.LT.2.17)GO TO 20
      IF(RPR.LT.2.17.AND.ROR.LT.2.17)GO TO 30
C
C     OBSERVER IN PLUME
C
   10 RPHALF=0.18*(RPR+0.25)+0.153*(RPR+0.75)+0.167*(RPR+1.5)
      IF(RPR.GT.0.5)GO TO 11
C
C     OBSERVER > 1/2 SIGMA-Y FROM CENTERLINE.
C
      YINTR1=(RPR/0.5)*0.18
      YINTRF=YINTR1
      YINTR=YINTRF+YINTRB
      RP=((RPR*YINTR1/2.+RPHALF)/YINTR)*(SY/1000.)
      GO TO 100
   11 IF(RPR.GT.1.0)GO TO 12
C
C     OBSERVER BETWEEN 1/2 AND 1 SIGMA-Y FROM CENTERLINE OF PLUME.
C
      YINTR1=((RPR-0.5)/0.5)*0.153
      YINTRF=YINTR1+0.18
      YINTR=YINTRF+YINTRB
      RP=(((RPR-0.5)/2.*YINTR1+RPHALF)/YINTR)*SY/1000.
      GO TO 100
   12 YINTR1=(RPR-1.0)*0.142
C
C     OBSERVER BETWEEN 1 AND 2.17 SIGMA-Y FROM CENTERLINE OF PLUME.
C
      YINTRF=YINTR1+0.18+0.153
      YINTR=YINTRF+YINTRB
      RP=((((RPR-1.)*YINTR1/2.+(RPR-0.75)*0.153+(RPR-0.25)*0.18+RPHALF
     1)/YINTR)*SY/1000.
      GO TO 100
   20 CONTINUE
C
C     OBSERVER OUTSIDE PLUME
C     ADJUST RPHALF FOR OBJECT WITHIN PLUME
C     RPFRNT FOR FRONT SIDE
C
      RPFRNT=(RPR-0.25)*0.18+(RPR-0.75)*0.153+(RPR-1.5)*0.167
      IF(ROR.GT.0.5)GO TO 21
      YINTR1=(ROR/0.5)*0.18
      YINTRB=YINTR1
      YINTR=YINTRB+YINTRF
      RP=((RPFRNT+(RPR+ROR/2.)*YINTR1)/YINTR)*SY/1000.
      GO TO 100
   21 IF (ROR.GT.1.0)GO TO 22
C
C     OBJECT BETWEEN 1/2 AND 1 SIGMA-Y FROM PLUME CENTERLINE.
```

SUBROUTINE PLMIN(RPR,ROR,SY,RP,YINTR)

```
C
      YINTR1=((ROR-0.5)/0.5)*0.153
      YINTRB=YINTR1+0.18
      YINTR=YINTRF+YINTRB
      RP=((RPFRNT+(RPR+(ROR-0.5)/2.)*YINTR1+(RPR+0.25)*0.18)/YINTR)*
     1 SY/1000.
      GO TO 100
 22   CONTINUE
C
C  OBJECT BETWEEN 1 AND 2.17 SIGMA-Y FROM PLUME CENTERLINE.
C
      YINTR1=(ROR-1.0)*0.142
      YINTRB=YINTR1+0.18+0.153
      YINTR=YINTRF+YINTRB
      RP=((RPFRNT+(RPR+(ROR-1.0)/2.)*YINTR1+(RPR+0.75)*0.153+(RPR+0.25)
     1 *0.18)/YINTR)*SY/1000.
      GO TO 100
 30   CONTINUE
C
C  BOTH OBSERVER AND OBJECT IN PLUME.
C
      IF(RPR.GT.0.5)GO TO 35
      IF(ROR.GT.0.5)GO TO 31
C
C BOTH OBSERVER AND OBJECT ARE WITHIN 0.5 SIGMA-Y OF THE PLUME CENTERLINE
C
      YINTR1=(RPR/0.5)*0.18
      YINTR2=(ROR/0.5)*0.18
      YINTR=YINTR1+YINTR2
      RP=((RPR*YINTR1/2.+(RPR+(ROR/2.))*YINTR2)/YINTR)*SY/1000.
      GO TO 100
 31   IF(ROR.GT.1.0)GO TO 32
C
C  OBJECT BETWEEN 0.5 AND 1.0 SIGMA-Y FROM CENTERLINE AND
C  OBSERVER < 0.5 SIGMA-Y FROM CENTERLINE OF PLUME.
C
      YINTR1=(RPR/0.5)*0.18
      YINTR2=((ROR-0.5)/0.5)*0.153
      YINTRB=YINTR2+0.18
      YINTR=YINTR1+YINTRB
      RP=((RPR*YINTR1/2.+(RPR+0.5+(ROR-0.5)/2.)*YINTR2+(RPR+0.25)*0.18)
     1 /YINTR)*SY/1000.
      GO TO 100
 32   YINTR1=(RPR/0.5)*0.18
C
C  OBJECT BETWEEN 1.0 AND 2.17 SIGMA-Y FROM CENTERLINE AND OBSERVER
C  < 0.5 SIGMA-Y FROM CENTERLINE.
C
      YINTR2=(ROR-0.5)*0.142
      YINTRB=YINTR2+0.153+0.18
      YINTR=YINTR1+YINTRB
      RP=((RPR*YINTR1/2.+(RPR+1.0+(ROR-1.)/2.)*YINTR2+(RPR+0.75)*0.153
     1 +(RPR+0.25)*0.18)/YINTR)*SY/1000.
      GO TO 100
 35   IF(RPR.GT.1.0)GO TO 40
      IF(ROR.GT.0.5)GO TO 36
C
C  OBJECT < 0.5 SIGMA-Y FROM CENTERLINE AND OBSERVER BETWEEN 0.5 AND
```

```
C   1.0 SIGMA-Y FROM CENTERLINE OF PLUME.
C
       YINTR1=((RPR-0.5)/0.5)*0.153
       YINTRF=YINTR1+0.18
       YINTR2=(ROR/0.5)*0.18
       YINTR=YINTRF+YINTR2
       RP=(((RPR-0.5)*YINTR1/2.+(RPR-0.25)*0.18+(RPR+ROR/2.)*YINTR2)
      1/YINTR)*SY/1000.
       GO TO 100
36     IF(ROR.GT.1.0)GO TO 37
C
C   BOTH OBSERVER AND OBJECT BETWEEN 0.5 AND 1.0 SIGMA-Y FROM
C   PLUME CENTERLINE.
C
       YINTR1=((RPR-0.5)/0.5)*0.153
       YINTRF=YINTR1+0.18
       YINTR2=((ROR-0.5)/0.5)*0.153
       YINTRB=YINTR2+0.18
       YINTR=YINTRF+YINTRB
       RP=(((RPR-0.5)*YINTR1/2.+(RPR-0.25)*0.18+(RPR+0.5+(ROR-0.5)/2.)
      1 *YINTR2+(RPR+0.25)*0.18)/YINTR)*SY/1000.
       GO TO 100
37     YINTR1=((RPR-0.5)/0.5)*0.153
C
C   OBSERVER BETWEEN 0.5 AND 1.0 SIGMA-Y FROM PLUME CENTERLINE AND OBJECT
C   BETWEEN 1.0 AND 2.17 SIGMA-Y FROM PLUME CENTERLINE.
       YINTRF=YINTR1+0.18
       YINTR2=(ROR-1.0)*0.142
       YINTRB=YINTR2+0.153+0.18
       YINTR=YINTRF+YINTRB
       RP=(((RPR-0.5)*YINTR1/2.+(RPR-0.25)*0.18+(RPR+1.0+(ROR-1.)/2.)
      1 *YINTR2+(RPR+0.75)*0.153+(RPR+0.25)*0.18)/YINTR)*SY/1000.
       GO TO 100
40     IF(ROR.GT.0.5)GO TO 41
C
C   OBSERVER BETWEEN 1.0 AND 2.17 SIGMA-Y FROM PLUME CENTERLINE AND
C   OBJECT < 0.5 SY FROM PLUME CENTERLINE.
C
       YINTR1=(RPR-1.0)*0.142
       YINTRF=YINTR1+0.18+0.153
       YINTR2=(ROR/0.5)*0.18
       YINTR=YINTRF+YINTR2
       RP=(((RPR-1.)*YINTR1/2.+(RPR-0.75)*0.153+(RPR-0.25)*0.18+(RPR+ROR/
      1 2.)*YINTR2)/YINTR)*SY/1000.
       GO TO 100
41     IF(ROR.GT.1.0)GO TO 42
C
C   OBSERVER BETWEEN 1.0 AND 2.17 SIGMA-Y FROM PLUME CENTERLINE AND OBJECT
C   BETWEEN 1.0 AND 1.5 SIGMA-Y FROM PLUME CENTERLINE.
C
       YINTRF=YINTR1+0.18+0.153
       YINTR2=((ROR-0.5)/0.5)*0.153
       YINTRB=YINTR2+0.18
       YINTR=YINTRF+YINTRB
       RP=(((RPR-1.0)*YINTR1/2.+(RPR-0.75)*0.153+(RPR-0.25)*0.18+(RPR+0.5
      1 +(ROR-0.5)/2.)*YINTR2+(RPR+0.25)*0.18)/YINTR)*SY/1000.
       GO TO 100
42     YINTR1=(RPR-1.0)*0.142
```

```
      SUBROUTINE PLMIN(RPR,ROR,SY,RP,YINTR)


C
C   BOTH OBSERVER AND OBJECT BETWEEN 1.0 AND 2.17 SIGMA-Y FROM PLUME
C   CENTERLINE.
C
        YINTRF=YINTR1+0.18+0.153
        YINTR2=(ROR-1.0)*0.142
        YINTRB=YINTR2+0.153+0.18
        YINTR=YINTRF+YINTRB
        RP=(((RPR-1.0)*YINTR1/2.+(RPR-0.75)*0.153+(RPR-0.25)*0.18+(RPR+1.0
       1 +(ROR-1.)/2.)*YINTR2+(RPR+0.75)*0.153+(RPR+0.25)*0.18)/YINTR)*SY/
       21000.
  100   RETURN
        END
PROGRAM SIZE:   PROCEDURE - 002176    LINKAGE - 000034    STACK - 000100
0000 ERRORS [<PLMIN >FTN-REV18.2]
```

FUNCTION ALGN(X,Y,Z)

```
(6159)        FUNCTION ALGN(X,Y,Z)
(6160)        TWOX = 2.*X
(6161)        U = (ALOG(Y/Z))**2
(6162)        ALGN = EXP(-U/TWOX)
(6163)        RETURN
(6164)        END
PROGRAM SIZE:    PROCEDURE - 000046     LINKAGE - 000032    STACK - 000056
0000 ERRORS [<ALGN  >FTN-REV18.2]
```

APPENDIX D

TWOSTR - AN ALGORITHM TO CALCULATE DIFFUSE SKY RADIANCE

APPENDIX D

TWOSTR - AN ALGORITHM TO CALCULATE DIFFUSE SKY RADIANCE

This appendix presents the mathematical model formulation that calculates the initial values of the diffuse sky radiance. These values are then incorporated into the radioactive transfer equation and integrated to provide the diffuse field component of the sky, or background object, radiance. The PLUVUE II subroutines that calculate the initial diffuse sky radiance are RAYREI and RAYSCT for the Rayleigh atmosphere cases and BACCLI and MGSCT for the other cases. The subroutines RAYSCT and MGSCT provide the Rayleigh and Henyey-Greenstein scattering functions, respectively. The subroutines RAYREI and BACCLI perform the diffuse sky radiance calculations according to the algorithm developed by Isaacs, which is presented in this appendix.

TWOSTR--An Algorithm to Calculate Diffuse Sky Radiance

Prepared by:
R. G. Isaacs

1. INTRODUCTION

This report describes an algorithm which evaluates the angular distribution of diffuse sky radiance (i.e., sky brightness) for a specified position of the sun, orientation of the observer, and optical properties of the atmosphere. This capability is generally required in mathematical models for the prediction of visibility impairment (Latimer et al., 1978). Within this context, the diffuse sky radiance distribution both provides a measure of the brightness of the background (i.e. unimpacted) sky and facilitates evaluation of the optical impact of an intervening plume due to extinction of background radiances and scattering of diffuse skylight (Isaacs and Özkaynak, 1980).

The theoretical basis for the calculation of diffuse skylight radiance is the radiative transfer equation for a multiple scattering atmosphere (Chandrasekhar, 1950; Coulson, 1971). While highly accurate numerical methods of solution are available (Hansen and Travis, 1974; Lenoble, 1977) and have been applied to skylight radiance calculations (Dave, 1980; Bergstrom et al., 1980a,b) they are computationally intensive. Consequently, simplified approaches to visibility model related radiative transfer theory were adopted (Latimer et al., 1978; Özkaynak et al., 1979). Based on examination of the potential errors and uncertainties associated with these approaches it was suggested that higher order approximate, yet analytical methods should be investigated (Bergstrom et al., 1980b, Isaacs, 1981). The particular treatment implemented in the computer code described below is based on a stream approximation developed by Kaufman (1979). Since the solution is algebraic rather than numerical, it is computationally efficient. It is to be emphasized, however, that the treatment is only approximate. Typical per cent error is evaluated relative to exact treatments for a variety of cases. It is suggested that implementation of this formalism enhances the depiction of physical reality in the radiative transfer submodel with little increase in computational level of effort and with associated errors consistent with the overall accuracy of related transport and dispersion submodels.

The code documented below is a user-oriented, FORTRAN subroutine with ten arguments consisting of nine input variables and one returned value. Five inputs provide wavelength dependent optical properties, three characterize the sun/observer geometric orientation, and one selects the desired atmospheric scattering properties. The calling program may select from among isotropic, Rayleigh, and Henyey-Greenstein phase functions. The returned value is the diffuse sky radiance for one solid angle sky element.

Listings and test cases are provided below.

2. THEORY

The wavelength-dependent radiance field, $I(\tau,\mu,\phi)$, in a plane parallel, multiple scattering atmosphere with a solar source function, J, is given by the solution to the radiative transfer equation:

$$\mu \frac{\partial I}{\partial \tau}(\tau,\mu,\phi) = I(\tau,\mu,\phi) - J(\tau,\mu,\phi) \qquad (1)$$

where

$$J(\tau,\mu,\phi) = \frac{F}{4} P(\mu,\mu_o,\phi,\phi_o)\, e^{-\tau/\mu_o} + \frac{1}{4\pi}\int_0^{2\pi}\int_{-1}^{+1} P(\mu,\mu';\phi,\phi')\, I(\tau,\mu',\phi')\,d\mu' d\phi' \qquad (2)$$

and the variables and parameters appearing above are:

τ	optical depth
μ	cosine of observer zenith angle
μ_o	cosine of solar zenith angle
ϕ	azimuth angle of observer
ϕ_o	azimuth angle of sun
πF	solar irradiance
P	scattering phase function of atmosphere

Of the approximate, analytical techniques available to solve (1) and (2), simple finite stream approximations are particularly convenient to use. A recent review of these methods is given in Meador and Weaver (1980). The method implemented in the code below is based on a recent extension

(Kaufman, 1979) to an earlier two stream formulation (Coakley and Chylik, 1975) which allows the specific azimuth/zenith angle dependence of the diffuse radiance to be approximated. This particular approach is well-behaved for optically thin atmospheres, a trait particularly valuable for treating problems at visible wavelengths. Physically, the approach is interpretable as an approximation of the multiply scattered contributions to the source function such that:

$$J_s(\tau, \pm \mu, \phi) \approx \frac{Fe^{-\tau/\mu o}}{4} P(\mu, \mp \mu_o; \phi, \phi_o)$$

$$+ \frac{I^+}{4\pi} \int_0^1 \int_0^{2\pi} P(\mu, \pm\mu'; \phi, \phi') \, d\mu' d\phi'$$

$$+ \frac{I^-}{4\pi} \int_0^1 \int_0^{2\pi} P(\mu, \mp \mu'; \phi, \phi') \, d\mu' d\phi' \qquad (3)$$

Equation (1) is written as two coupled relations:

$$\mu \frac{dI^+}{d\tau} = I^+ - \frac{I^+}{4\pi} \int_0^{2\pi} \int_0^1 P(\mu, + \mu'; \phi, \phi') \, d\mu' d\phi'$$

$$- \frac{I^-}{4\pi} \int_0^{2\pi} \int_0^1 P(\mu, - \mu'; \phi, \phi') \, d\mu' d\phi'$$

$$- \frac{F}{4} P(\mu, - \mu_o : \phi, \phi_o) \, e^{-\tau/\mu o} \qquad (4)$$

$$- \mu \frac{dI^-}{d\tau} = I^- - \frac{I^+}{4\pi} \int_0^{2\pi} \int_0^1 P(\mu, - \mu'; \phi, \phi')\, d\mu'\, d\phi'$$

$$- \frac{I^-}{4\pi} \int_0^{2\pi} \int_0^1 P(\mu, \mu'; \phi, \phi')\, d\mu'\, d\phi'$$

$$- \frac{F}{4} P(\mu, \mu_0; \phi, \phi_0)\, e^{-\tau/\mu_0} \qquad (5)$$

The angular integrations in (4) and (5) are performed by noting the phase function normalization:

$$\omega_0 = \frac{1}{4\pi} \int_0^{2\pi} \int_{-1}^{+1} P(\mu, \mu'; \phi, \phi')\, d\mu'\, d\phi' \qquad (6)$$

and defining the azimuthally symmetric function, P^o; the backscatter fraction for monodirectional radiation, $\beta(\mu)$; and the backscatter fraction for isotropic radiation, β' as:

$$P^o(\mu, \mu') = \frac{1}{2\pi} \int_0^{2\pi} P(\mu, \mu'; \phi, \phi')\, d\phi' \qquad (7)$$

$$\beta(\mu) = \frac{1}{2\omega_0} \int_0^1 P^o(\mu, \mu')\, d\mu' \qquad (8)$$

$$\beta' = \int_0^1 \beta(\mu')\, d\mu' \qquad (9)$$

Upon substitution of (6, 7, 8, 9) into (4) and (5) they become:

$$\mu \frac{dI^+}{d\tau} = I^+ - I^+ \omega_o [1-\beta(\mu)] - I^- \omega_o \beta(\mu)$$

$$- \frac{F}{4} P(\mu,-\mu_o;\phi,\phi_o) e^{-\tau/\mu_o} \qquad (10)$$

$$- \mu \frac{dI^-}{d\tau} = I^- - I^+ \omega_o \beta(\mu) - I^- \omega_o [1-\beta(\mu)]$$

$$- \frac{F}{4} P(\mu,\mu_o;\phi,\phi_o) e^{-\tau/\mu_o} \qquad (11)$$

Assuming that the scattered diffuse intensities are given by the fluxes $F^{\pm}(\tau)$ such that:

$$I^{\pm} (\tau,\mu,\phi) = F^{\pm}(\tau)/\pi \qquad (12)$$

equations (10) and (11) become:

$$\mu \frac{dI^+}{d\tau} - I^+ = - \frac{\omega_o}{\pi} \left\{ F^+[1-\beta(\mu)] + F^- \beta(\mu) \right\} \qquad (13)$$

$$- \frac{F}{4} P(\mu,-\mu_o;\phi,\phi_o) e^{-\tau/\mu_o}$$

$$- \mu \frac{dI^-}{d\tau} - I^- = - \frac{\omega_o}{\pi} \left\{ F^+ \beta(\mu) + F^- [1-\beta(\mu)] \right\}$$

$$- \frac{F}{4} P(\mu,\mu_o;\phi,\phi_o) e^{-\tau/\mu_o} \qquad (14)$$

Integrating (13) and (14) over the angle μ yields corresponding flux equations:

$$\frac{dF^+}{d\tau} = 2F^+ \left[1-\omega_0(1-\beta')\right] - 2F^- \omega_0\beta' - \pi F\omega_0\beta(\mu_0)\, e^{-\tau/\mu_0} \qquad (15)$$

$$\frac{dF^-}{d\tau} = -2F^-\left[1-\omega_0(1-\beta')\right] + 2F^+ \omega_0\beta' + \pi F\omega_0\left[1-\beta(\mu_0)\right] e^{-\tau/\mu_0} \qquad (16)$$

which may be solved subject to the boundary conditions:

$$\left.\begin{aligned} F^-(\tau=o) &= 0 \\ F^+(\tau=\tau^*) &= r\left[\pi\, \mu_0\, e^{-\tau^*/\mu_0} + F^-(\tau=\tau^*)\right] \end{aligned}\right\} \qquad (17)$$

at the top ($\tau = 0$) and bottom ($\tau = \tau^*$) of the atmosphere. The surface is assumed to be a Lambert reflector with albedo, r. The solutions for F are:

$$F^+(\tau) = Ae^{k\tau} + Be^{-k\tau} + Ce^{-\tau/\mu_0} \qquad (18)$$

$$F^-(\tau) = \frac{1}{\gamma_2}\left\{ A(\gamma_1-k)e^{k\tau} + B(\gamma_1+k)e^{-k\tau} + Ye^{-\tau/\mu_0} \right\} \qquad (19)$$

where the appropriate constants are given by:

$$\gamma_1 = 2\left[1-\omega_0(1-\beta')\right] \qquad (20)$$

$$\gamma_2 = 2\,\omega_0\beta' \qquad (21)$$

$$k = (\gamma_1^2 - \gamma_2^2)^{1/2} \tag{22}$$

$$A = [B(\gamma_1+k) + Y]/(k-\gamma_1) \tag{23}$$

$$B = (E_1 e^{k\tau^*} + E_2 e^{-\tau^*/\mu_o})/(E_3 e^{k\tau^*} + E_4 e^{-k\tau^*}) \tag{24}$$

$$C = \pi F \omega_o \left\{ \frac{\beta(\mu_o)}{\mu_o} - \gamma_1 \beta(\mu_o) - \gamma_2[1-\beta(\mu_o)] \right\} \times \left(\frac{\mu_o^2}{1-k^2\mu_o^2} \right) \tag{25}$$

$$Y = C\left(\gamma_1 + \frac{1}{\mu_o}\right) - \pi F \omega_o \beta(\mu_o) \tag{26}$$

$$E_1 = Y\,[1/(\gamma_1-k) - r/\gamma_2] \tag{27}$$

$$E_2 = \left[- C + \pi F \mu_o r + \frac{rY}{\gamma_2}\right] \tag{28}$$

$$E_3 = (\gamma_1 + k)[1/(k-\gamma_1) + r/\gamma_2] \tag{29}$$

$$E_4 = [1 - r(\gamma_1+k)/\gamma_2] \tag{30}$$

The required downward diffuse radiance, $I^-(\tau^*,\mu,\phi)$, is given solving (13) and (14) using the flux solutions above to yield:

$$I^-(\tau^*,\mu,\phi) = E_1 e^{-\tau^*/\mu} + \frac{W_1 e^{k\tau^*}}{1-\mu k} + \frac{W_2 e^{-k\tau^*}}{1+\mu k} + \frac{W_3 e^{-\tau^*/\mu}}{1+\mu/\mu_o} \tag{31}$$

where:

$$E_1 = -\left(\frac{W_1}{1-\mu k} + \frac{W_2}{1+\mu k} + \frac{W_3}{1+\mu/\mu_o}\right) \tag{32}$$

$$W_1 = \frac{\omega_o}{\pi} A \frac{(1-\mu k)}{(1+\mu k)} \left[\beta(\mu) + \frac{[1-\beta(\mu)](\gamma_1-k)}{\gamma_2}\right] \tag{33}$$

$$W_2 = \frac{\omega_o}{\pi} B \frac{(1+\mu k)}{(1-\mu k)} \left[\beta(\mu) + \frac{[1-\beta(\mu)](\gamma_1+k)}{\gamma_2}\right] \tag{34}$$

$$W_3 = \frac{(\mu_o+\mu)}{(\mu_o-\mu)} \left[\frac{\omega_o}{\pi} \beta(\mu)\ C + \frac{\omega_o}{\pi} [1-\beta(\mu)] \frac{Y}{\gamma_2} + \frac{F}{4} P(\mu,\mu_o,\phi)\right] \tag{35}$$

Values of the required backscatter functions β' and $\beta(\mu)$ are obtained upon substitution of the appropriate scattering phase function, P, into equations (7), (8), and (9). Options are provided in the algorithm described below to treat isotropic, Rayleigh, and Henyey-Greenstein phase functions.

2.1 Isotropic scattering

For isotropic scattering:

$$p(\mu,\mu';\phi,\phi') = \omega_o \tag{36}$$

this yields:

$$P^{\circ}(\mu,\mu') = \frac{1}{2\pi}\int_0^{2\pi} P(\mu,\mu';\phi,\phi')d\phi' = \omega_o \tag{37}$$

$$\beta(\mu) = \frac{1}{2\omega_o}\int_0^{1} P^{\circ}(\mu,-\mu')d\mu' = \frac{1}{2} \tag{38}$$

and

$$\beta' = \int_0^1 \beta(\mu)d\mu = \frac{1}{2} \qquad (39)$$

2.2 Rayleigh scattering

The Rayleigh phase function is:

$$p(\mu,\mu';\phi,\phi') = \frac{3}{4}\,[1 + \mu^2\mu'^2 + (1-\mu^2)(1-\mu'^2)\cos^2(\phi-\phi')$$
$$+ 2\mu\mu'(1-\mu^2)\frac{1}{2}(1-\mu'^2)\frac{1}{2}\cos(\phi-\phi')] \qquad (40)$$

Upon substitution into (7), (8) and (9) this yields:

$$p^\circ(\mu,\mu') = \frac{3}{4}\,[1 + \mu^2\mu'^2 + \frac{1}{2}(1-\mu^2)(1-\mu'^2)] \qquad (41)$$

$$\beta(\mu) = \frac{1}{2\omega_o} \qquad (42)$$

$$\beta' = \frac{1}{2\omega_o} \qquad (43)$$

To avoid singularities in eigen functions of (18) and (19), for Rayleigh scattering the program assumes that $\omega_o = .99999$ and, therefore, $\beta(\mu) = \beta(\mu_o) = \beta' = .500005$.

2.3 Henyey-Greenstein phase function

The Henyey-Greenstein phase function used is:

$$p(\mu,\mu';\phi,\phi') = \omega_o(1-g^2)/[1+g^2-2g(\mu\mu'$$
$$+ (1-\mu^2)\frac{1}{2}(1-\mu'^2)\frac{1}{2}\cos(\phi-\phi')\frac{3}{2}] \qquad (44)$$

where g is the asymmetry factor.

Backscatter fractions β' and $\beta(\mu)$ are introduced by digitizing values obtained by Wiscombe and Grams (1976) whose Figure 3 provides curves as a function of asymmetry factor g for various values of μ.

3. PROGRAM DESCRIPTION

The equations discussed in the previous section are implemented in a FORTRAN subroutine called TWOSTR. Table 1 provides a list of the FORTRAN variable names of the arguments of this subroutine, their definitions, and the corresponding symbols used in Section 2.

For each call to the subroutine, the wavelength dependent optical properties of the atmosphere (Tϕ, Wϕ, G), solar irradiance (F9), and surface albedo (A1) must be provided in addition to selecting the desired scattering function (K1).

For a specified solar zenith angle cosine (Uϕ), one value of the diffuse downward sky radiance (I2) is returned for the solid angle element in the vicinity of observed zenith angle cosine (U) and azimuth angle difference (D). When the wavelength-dependent solar irradiance (F9) is given in units of $\mathrm{mWcm^{-2}\mu m^{-1}}$, for example, the radiance is in $\mathrm{mWcm^{-2}\mu m^{-1}sr^{-1}}$.

4. ACCURACY

It is important to reemphasize that the results of the program described above are only approximate. Selected

Table 1

FORTRAN Variable Names, Definition, and Parameters Described in Section 2.

FORTRAN Variable	Definition	Symbol (see Section 2)
F9	solar irradiance	πF
T0	total optical depth	τ^*
A1	surface albedo	r
K1	scattering function parameter = 1 (isotropic) = 2 (Rayleigh) = 3 (H - G)	
U	observer zenith angle cosine	μ
U0	solar zenith angle cosine	μ_o
W0	single scattering albedo	ω_o
G	asymmetry factor	g
D	azimuth angle difference (degrees)	$\phi-\phi_o$
I2	downward intensity (returned value)	$I^-(\tau^*,\mu,\phi)$
B0	backscatter fractions	$\beta(\mu_o)$
B1		β'
B2		$\beta(\mu)$

comparisons with exact solutions and highly accurate numerical calculations have been made where appropriate to assess the magnitude of the error. A sampling of these results are presented below.

4.1 Isotropic scattering

For isotropic scattering exact solutions to the radiative transfer equation exist using Chandrasekhar's (1950) X and Y functions (Carlstedt and Mullikan, 1966). Table 2 provides a comparison of these values to those obtained from the stream approximation assuming an overhead sun ($\mu_0 = 1.0$), zero surface albedo ($r = 0.0$), single scattering albedo ($\omega_0 = 0.5$) and solar irradiance $\pi F = \pi$. While accuracies are generally high, isotropic scattering does not describe the real atmosphere.

4.2 Rayleigh scattering

When aerosols are absent the scattering properties of the atmosphere are given by the Rayleigh scattering function. To a first approximation, this form of scattering may be taken to characterize so-called ultraclean (i.e. high visual range) atmospheres. Isaacs (1981) reported on comparisons between the stream approximation and highly accurate numerical calculations from Coulson et al. (1960). These percentage errors are provided in Table 3.

Table 2

Comparison of Exact (X,Y Functions) and Approximate (Kaufman, 1979) Diffuse Downward Radiances for Isotropic Scattering

τ^*	μ			
	0.2	0.6	0.9	
0.4	3.33(-2)	1.95(-2)	1.45(-2)	E
	3.18(-2)	1.85(-2)	1.38(-2)	SA
	4.8	5.0	4.9	Δ%
1.0	2.70(-2)	2.62(-2)	2.25(-2)	E
	2.65(-2)	2.55(-2)	2.19(-2)	SA
	1.8	2.6	2.7	Δ%
3.5	3.42(-3)	5.89(-3)	7.89(-3)	E
	3.33(-3)	5.88(-3)	7.91(-3)	SA
	2.5	<1.0	<1.0	Δ%

E	exact X,Y functions (Carlstedt and Mullikan, 1966)
SA	stream approximation (Kaufman, 1979)

Table 3. Percent error of single scattering (SS) and stream approximation (SA) approaches over sky quadrant ($o \leq \mu \leq 1$; $0 \leq \phi \leq 180°$) for a solar elevation angle of 53° for optical depths of 0.05(a), 0.10(b), and 0.25(

(a) $\tau^* = 0.05$

	r = 0.0				r = 0.25				
φ=	0	60	120	180	0	60	120	180	
μ=									
.06	9.2	10.2	10.4	9.4	32.8	37.6	38.7	34.4	SS
	4.8	4.8	4.7	4.6	3.7	3.5	3.3	3.5	SA
.28	8.9	9.8	10.4	9.5	29.9	35.0	39.6	37.0	SS
	5.1	4.9	4.3	4.1	3.9	3.6	2.9	2.8	SA
.64	8.3	9.8	9.4	9.2	26.9	30.8	37.7	39.0	SS
	5.1	4.8	3.7	3.1	4.1	3.7	2.6	2.1	SA
.96	7.8	8.1	8.2	8.2	27.2	28.6	31.4	32.7	SS
	4.6	4.4	3.9	3.6	3.6	3.4	2.9	2.6	SA

(b) $\tau^* = 0.10$

	r = 0.0				r = 0.25				
φ=	0	60	120	180	0	60	120	180	
μ=									
.06	15.5	17.1	17.3	15.7	37.1	41.8	42.9	38.6	SS
	7.1	6.7	6.4	6.7	5.6	5.1	4.8	5.2	SA
.28	14.8	16.2	17.2	16.0	33.8	38.7	43.1	40.5	SS
	7.6	7.1	5.8	5.6	5.9	5.2	4.0	4.0	SA
.64	13.9	14.7	15.8	15.5	30.7	34.4	41.0	42.2	SS
	7.8	7.1	4.9	3.9	6.3	5.4	3.4	2.6	SA
.96	13.2	13.4	13.6	13.6	30.7	32.0	34.6	35.9	SS
	6.9	6.4	5.5	4.9	5.4	5.0	4.0	3.5	SA

(c) $\tau^* = 0.25$

	r = 0.0				r = 0.25				
φ=	0	60	120	180	0	60	120	180	
μ=									
.06	29.5	32.2	32.6	30.1	47.7	52.4	53.3	49.2	SS
	10.3	8.8	8.2	9.4	8.3	6.8	6.3	7.4	SA
.28	28.1	30.6	32.4	30.5	43.0	47.7	51.7	49.2	SS
	11.9	10.2	7.5	7.6	9.5	7.8	5.4	5.6	SA
.64	26.5	27.9	30.1	29.9	39.6	43.2	49.1	50.1	SS
	12.6	11.0	6.5	4.5	10.3	8.6	4.7	3.1	SA
.96	25.5	25.8	26.4	26.6	39.3	40.4	42.8	43.9	SS
	11.0	10.1	8.1	7.0	8.9	8.1	6.2	5.2	SA

4.3 Aerosol scattering

The most stringent test of a multiple scattering treatment is presented by aerosol scattering. Table 4 presents results from highly accurate spherical harmonic numerical calculations reported in Lenoble (1977) and the stream approximation assuming zero surface albedo ($r = 0.0$), optical depth of unity ($\tau^* = 1.0$), and Deirmendjian's (1969) haze L. This optical depth corresponds to quite a hazy atmosphere with visual range of about 5 km.

As illustrated by the spherical harmonic results, sky radiances vary considerably over the sky hemisphere. The "average diffuse intensity" approximation (see Bergstrom et al. 1980b) would yield a sky radiance distribution uniform in the angle μ. The stream approximation (SA) tries to reproduce the dependence illustrated by the accurate numerical calculation above but under estimates radiances toward the sun's position and overestimates these away from the sun (see cases 1 and 2). When the sun is not at zenith (case 3), diffuse sky radiances toward the sun ($>\phi = 0$) are underestimated while those away from the sun's position ($>\phi = 90, 180°$) are increasingly overestimated.

Table 4. Comparison of radiances calculated using spherical harmonics (SH) multiple scattering method and stream approximation (SA) in a hazy aerosol (Deirmendjian haze L) atmosphere. (Optical depth, $\tau^* = 1.0$; asymmetry factor; $g = .8042$; solar flux $\pi F = \pi$.)

			μ					
	ω_o	μ_o	0.2	0.4	0.6	0.8	1.0	
Case 1								
	1.0	1.0	.176	.199	.256	.468	3.368	SH
			.385	.378	.366	.425	2.799	SA
			-119	-90	-43	+9	+17	Δ%
Case 2								
	0.9	1.0	.124	.148	.201	.387	2.970	SH
			.289	.289	.285	.344	2.490	SA
			-133	-95	-42	+11	+16	Δ%
Case 3								
	0.9	0.5	1.291	2.401	2.153	.720	-	SH
	(Δφ = 0°)		.579	2.157	2.063	.427	-	SA
			+55	+10	+4	+40	-	Δ%
	0.9	0.5	.101	.099	.089	.083	-	SH
	(Δφ = 90°)		.185	.185	.170	.155	-	SA
			-83	-87	-91	-87	-	Δ%
	0.9	0.5	-	.045	.036	.033	-	SH
	(Δφ = 180°)		-	.176	.159	.143	-	SA
			-	-291	-340	-333	-	Δ%

SH Spherical harmonics (see Lenoble, 1977)
SA Stream approximation (Kaufman, 1979)

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